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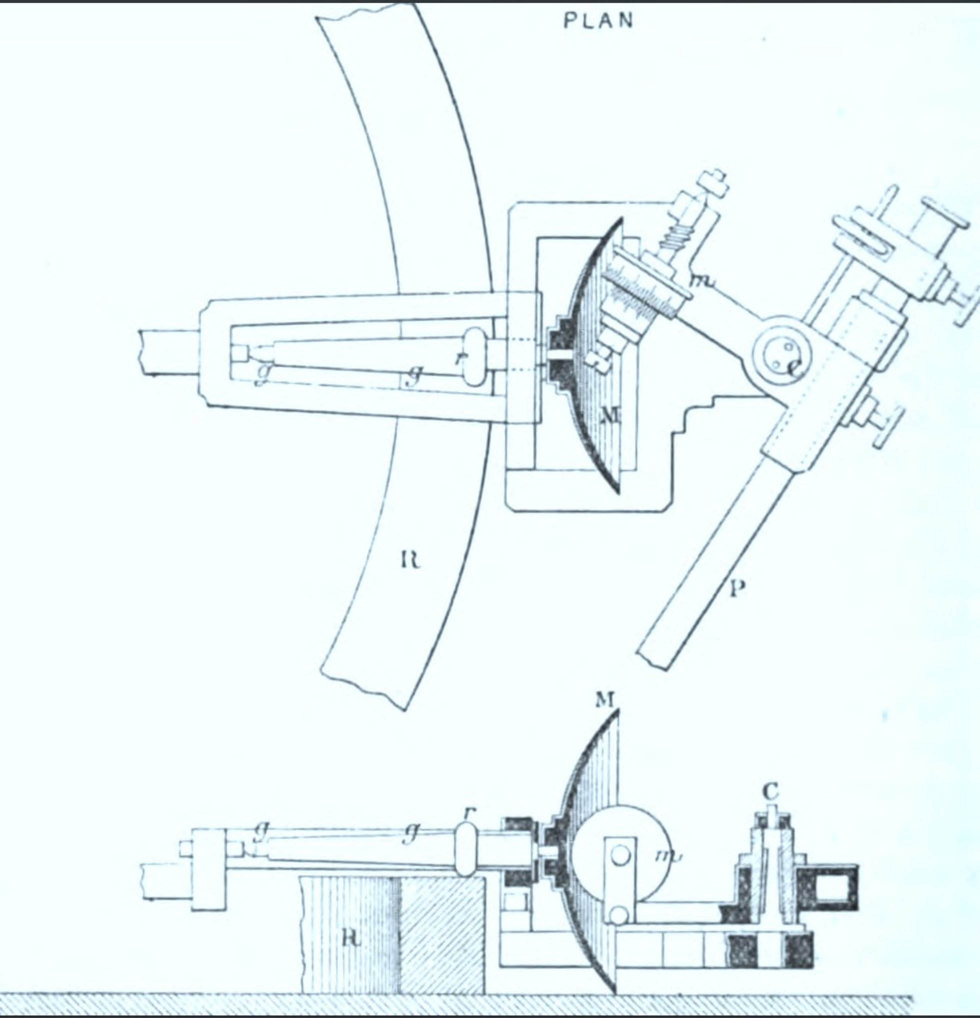
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Minutes of proceedings of the Institution of Civil Engineers

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXXII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. lxxx., p. 204, Table I., column 6, line 1, *for* "64,000" *read* "6,400."
„ „ p. 208, line 22, *for* "River Movena" *read* "River Morna."
„ „ „ line 25, the sign between the two terms of the equation should be + and not "×," so that the right hand member of the equation should read:—

$$= 440\ \mathrm{N} \left(6 \log \frac{8 \times 18\tfrac{1}{2}^2}{6} + 32 \log \frac{8 \times 35^2}{34}\right)$$

„ „ p. 326, line 21, the sign between the two members of the second member of this equation should be + and not ×, so that it should read:—

$$Q = (l - 3)\ 3 \cdot 43\, h \frac{10}{7} + 9 \cdot 13\, h \frac{10}{7}$$

„ „ „ line 23 should oommence with sign = and not —, and read

$$= 3 \cdot 43\, (l - 0 \cdot 34)\, h \frac{10}{7}.$$

„ „ p. 429, line 11, *for* "4 lbs." *read* "40 lbs."
Vol. lxxxi., p. 384, line 21, *for* "carbolic" *read* "carbonic."
„ „ „ „ 23, *for* "thin" *read* "this."
„ „ p. 386 „ 10, *for* "five lamps" *read* "fire lumps."
„ „ „ „ 16, *for* "lamps" *read* "lumps."
„ „ p. 387 „ 3, *for* "superheated" *read* "sulphuretted."
„ „ „ „ 13, *for* "with hard porcelain-like pigments" *read* "into hard porcelain-like filaments."
„ „ „ „ 21, *for* "2*d*." *read* "2·4*d*."
„ „ „ „ 26, *for* "3*s*. 3*d*." *read* "3·3*d*."
„ „ p. 390 „ 17 from bottom, *for* "3 feet" *read* "5¼ feet."
„ „ p. 391, in Table make the following alterations:—
„ „ „ "Root" col., *for* "468·9" *read* "502·5."
„ „ „ „ „ *for* "9·4" *read* "10."
„ „ „ „ „ *for* "7·99" *read* "7·45."
„ „ „ „ „ *for* "10·43" *read* "10·32."
„ „ „ "Harrison" col., *for* "11·23" *read* "9·25."
„ „ „ "Dickson" col., *for* "6·75" *read* "6·83."
„ „ „ „ „ *for* "9·45" *read* "8·06."
„ „ „ "Baldwin" col., *for* "8·26" *read* "7·40."
„ „ „ In last line of Table, *for* "Steam-*power* in boiler" *read* "Steam-*room* in boiler."
„ „ „ „ add prefix "cubic feet."
„ lxxxii., Plate 6 (some impressions), *for* "Reopened North Jetty," *read* "Proposed North Jetty," and the dotted line should not have been carried below the "R" of Bay of Rest, so as to leave an opening for the harbour.

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1884–85.—PART IV.

Sect. I.—MINUTES OF PROCEEDINGS.

---

14 April, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

George Buchanan.
William Rhodes.
George Hennet Ross.

The following Candidates have been admitted as

Students.

James Adam.
Albert Ernest Austin.
James Picton Baillie.
Alan Neville Banister.
Herbert Alfred Lucas Barry.
John Watkins Brough.
Arthur Richard Brown.
Alexander Edward Chapman.
Francis James Cochrane.
John Davis Cotesworth.
Sidney A Court.
Thomas Travers Dixon.
Claude Francis Arthur Egerton.
George Eraut, Jun.
Douglas John Gillon.
John Goodman.
Francis William Hardwick, B.A.
Harry Kellett.
Charles Philip King.
William Lynch.
Henry Allan Moss.
Godfrey Bowen Partridge.
Thomas Pope.
Henry Simmonds.
Arthur Drew Thomas.
Charles Campbell Wardrop.

The following Candidates were balloted for and duly elected as

Members.

Walter Bulkeley Coventry.
John Hopkinson.
Archibald Henry Irvine.
Charles Le Lievre.
James Walker.
John Arthur Wright.

Associate Members.

Harold William Abernethy.
Justin Victor Wilfrid Amor.
Joseph Devonport Finney Andrews.
Andrew George Ashcroft, Stud. Inst. C.E.
Robert Aytoun.
William Christopher Barley.
William Bean.
Harry John Toler Bennett.
Charles Henry Blackburn, Stud. Inst. C.E.
Frank Brewer, Stud. Inst. C.E.
The Hon. Reginald Thomas Dudley Brougham.
Matthew Joseph Butler.
William Butterton, Jun.
James Cameron.
Albert Johnstone Campbell.
Edward Glover, M.A., B.E.
Hugh Erat Harrison, B.Sc.
Christopher Little, Stud. Inst. C.E.
George Vincent Maxted, Stud. Inst. C.E.
Michael Nethersole, Stud. Inst. C.E.
William Baker Ollis.
Henry Ough.
Ernest Samuel Prentice, Stud. Inst. C.E.
Ernest Van Putten, Stud. Inst. C.E.
Thomas Noble Ritson.
John Pemberton Stubbs.
Archibald Alexander Swan.
Percy Tarbutt.
Sam Tomlinson, Stud. Inst. C.E.
George Watkeys.

Associates.

Henry Spencer Palmer, *Lieut.-Col.*, R.E.
Nowrojee Pestonjee.
Theophilus George Wright.

(*Paper No. 2069.*)

"On Rivers flowing into Tideless Seas, illustrated by the River Tiber."

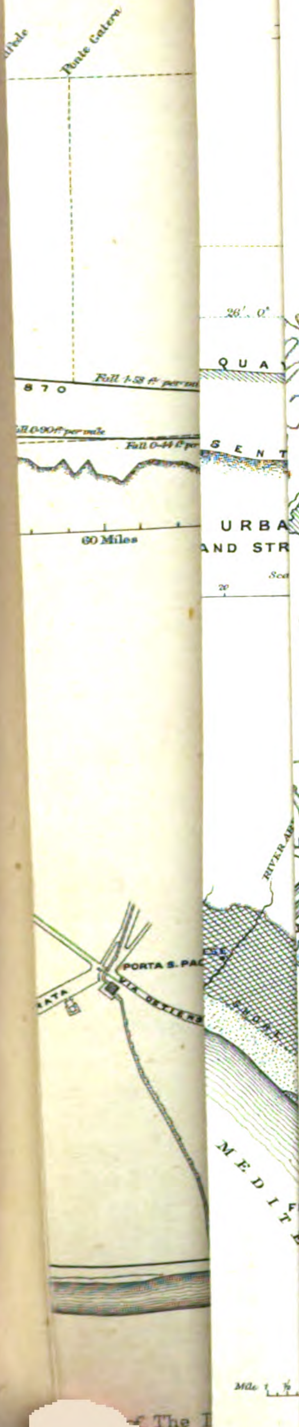
By William Shelford, M. Inst. C.E.

The treatment of tidal rivers, as distinguished from that of rivers running into tideless seas, is particularly a British subject. Not only is the seaboard of Great Britain and Ireland far greater than that of any other country in Europe, but the shores of the British possessions abroad are for the most part washed by tidal seas. Moreover, the earlier Presidents of The Institution of Civil Engineers, and those who developed the profession of Civil Engineering in England, advanced from the construction of canals to the execution of the greater works required in the adaptation of tidal rivers to an increasing navigation, and made the subject their own by establishing at least one principle of improvement which has ever since been recognized as sound, viz., the principle of "carrying low-water at sea as far inland as possible."

In British practice the improvement in tidal rivers has been so far effected mainly for the accommodation of vessels of deep draught;

PLATE.1.

Fig: 8.



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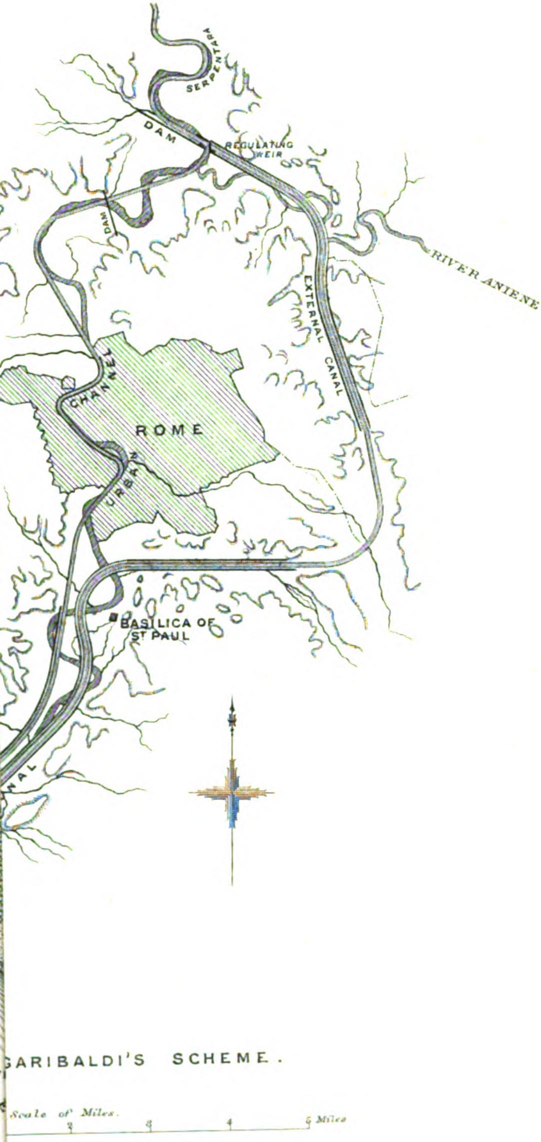

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ARIBALDI'S SCHEME.

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and the primary function of a river—the discharge of water from the area within its watershed—has been either treated as secondary to navigation, or has been more or less performed by the works which were required in the interests of navigation.

In continental practice, on the other hand, rivers which run into tideless seas have been studied with especial reference to the discharge of fresh-water floods, and, with some notable exceptions, their navigation for sea-going craft has been subordinated to their capacity for drainage.

POINTS OF DIFFERENCE BETWEEN TIDAL AND NON-TIDAL RIVERS.

Delta.—Tidal rivers have no true deltas, but the detritus which they carry is kept by the ebb and flow of the tides in constant agitation, and is dispersed, unless the configuration of the coast or the set of the tides causes its accretion in a form approaching a delta. The Humber, the most muddy river in England, has no delta. The Tiber, with less drainage area, has an important delta, and larger tideless rivers, as the Danube and the Nile, have deltas of 50 and 100 miles in width respectively.

Flood-Reservoir.—In tidal rivers the maximum flood-channel necessary for the discharge of fresh-water floods is maintained by the regular action of the tides. The tidal reservoir is always in excess of the capacity required for the passage of fresh-water floods through it, and is regularly filled with fresh water and salt water in varying proportions, just as the one or the other may be available for maintaining the tidal action.

In non-tidal rivers the flow is irregular, and continues small for the greater part of every year. The maximum flood occurs often at intervals of several years, and at such times the stream is unusually rapid, far exceeds its accustomed bounds, creates alarm, and is discharged through a channel more or less unprepared for the emergency.

Navigation.—Tidal rivers are more convenient for navigation, even when their outfalls are encumbered by sands, because under all circumstances the lift of the tide is available for ships entering them. Thus where bars are formed by the transverse action of the sea, or by any other external cause—which may occur at either a tidal or a tideless outfall—navigation is possible in the one case and impossible in the other.

At Liverpool, for instance, with an insufficient depth of 9 feet at low water on the bar, the largest vessels can pass as the tide rises without the aid of any engineering works at the entrance to improve the depth; while in the Danube a similar depth of 9 feet had to be increased to 20 feet by great works executed at the Sulina mouth, from the designs of Sir Charles A. Hartley, K.C.M.G., M. Inst. C.E. Again the still larger Mississippi had but a maximum depth of somewhat less than 9 feet on the bar till the training works of Mr. J. B. Eads, M. Inst. C.E., increased it to 30 feet through the South Pass.

These are examples of the first magnitude. If smaller ones were considered the superiority of tidal rivers would be found to be much greater.

Recuperative Power.—The difference between tidal and non-tidal rivers is not less striking in natural conservation, or recuperative power. When a tidal river is in the worst possible condition, and is choked by shifting sands, it still serves as an outlet for the natural drainage of the country, by means of a tortuous channel on the ebb tide. But when the stream is reversed by the approach of the flood-tide, the greater the sinuosities the greater the friction in the channel, and consequently the greater also the head of the wave and the scouring power of the current; so that the flood-tide is not long confined to the tortuous ebb-channel, but breaks through the sands, and thus forms a new and straightened channel through which the ebb returns and continues to flow till it has reproduced the original conditions, or this action may commence with the ebb. An excellent illustration of it, and of the recuperative power of an estuary when choked with sand notwithstanding the absence of engineering works, is the Upper Mersey, some varying channels of which are shown in Plate 1, Fig. 1.

Non-tidal rivers have no such recuperative power, but their sinuosities tend to increase in perpetuity.

Rise of River-Bed.—A river which is free from tides is also subject to the disadvantages arising from the constant extension of its delta, the effect of which is to remove the point of discharge into the sea further seaward and to diminish the inclination of the surface of the stream.

Now assuming that the capability of a stream for moving substances varies as the sixth power of its velocity, which the Author believes to have been first calculated by Mr. Wilfrid Airy, M. Inst. C.E., and afterwards by Mr. A. H. Shield, Stud. Inst. C.E., and which agrees with the experiments of the late Mr. T. E. Blackwell,[1] M. Inst. C.E.; and considering that the velocity varies as the square root of the fall or declivity of the surface, *other conditions remaining the same*, it follows that the scouring power of a stream varies as the cube of the fall. Any reduction in the fall will therefore tend to disproportionately reduce the scouring power, and to cause a deposit in the bed of the stream, commencing at the outfall.

---

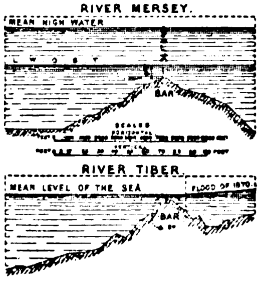
[1] Report of the Referees upon the Main Drainage of the Metropolis, July 31, 1857. Appendix IV.

In tidal rivers there is often the same tendency to form deposit; but the constant flux and reflux of the great volume of water afford abundant opportunity for its removal by scour—an opportunity which only occurs in a non-tidal river when an occasional flood fills its channel, and which is not so well under control.

The scour of a tidal river also operates to reduce the bar formed by the sea at the outfall; but at the delta of a non-tidal river there is the same tendency to the formation of a bar *minus* the means of reducing it. Fig. 1 shows comparative sections of the bars at the mouths of the Mersey and of the Tiber and the depth of water over them.

Currents at Sea.—Lastly, the ebb-tide from a tidal river is as a rule only a branch of the great tidal stream outside; but a river discharging into a tideless sea has to force its way into slack water.

FIG. 1.



METHODS OF IMPROVEMENT.

In river engineering the fundamental conditions to be studied are at the outfall.

Non-tidal rivers are in all points of difference at a disadvantage compared with those in which a good tidal action either exists or can be induced, and particularly at their outfalls. They are subject to the influences of an excessive variation in the quantity of water to be discharged, and if improved would require to be provided with a channel capable both of conveying the maximum quantity and of being maintained by the average stream. Such conditions are incompatible. It results therefore that in small rivers there is a wide and very shallow mouth, unfit for navigation; while in larger rivers, such as the Mississippi, the Danube, the Tiber and others, one branch is selected and made navigable for ships of such draught as an average channel can be maintained for, and the others are treated as flood overflows.

But whilst the navigation in non-tidal rivers is thus very limited, the conditions are even worse for effecting any improvement in the discharge of floods; for a large body of water cannot be discharged until it has become dammed up sufficiently to scour for itself a channel through the delta, and to overcome the inertia of the slack water of the sea. For the purpose of improvement, therefore, in the discharge of floods, the operations must be confined to the river itself, and the improvement works will consist of either (*a*), raising the banks on both sides; or (*b*), straightening the course of the river, and lowering the water-line.

The River Tiber, from its ancient history and the recent investigations as to the means of protecting Rome from inundation, affords one of the best opportunities of considering these modes of improvement.[1] The Author is indebted to the Right Honourable Lord Waveney for the opportunity of examining and reporting upon that river from the mountains to the sea, and for permission to lay the information thus acquired before the Institution.

THE RIVER TIBER.

"The Tiber rises nearly due east of Florence, and on the opposite side of the ridge of the Appenine mountains which gives birth to the Arno"[2] at a height of 1,160 metres (3,805 feet) above the Mediterranean. At a distance of 120 kilometres (75 miles) it passes the town of Perugia, which has an elevation of 482 metres (1,581 feet). At 245 kilometres (152 miles) it is joined by its most important affluent, the Nera, near the town of Orte, at an elevation of about 50 metres (164 feet). The Nera and its branches drain a large area on the western slopes of a mountain-chain which reaches an elevation of 2,377 metres (7,798 feet) at its source, at a distance of about 130 kilometres (80 miles) from its junction with the Tiber. It has an average fall of about 18 metres per kilometre (95 feet per mile). At 345 kilometres (214 miles) the Tiber is joined by another important affluent, the Anio, or Aniene, immediately above Rome, whence it continues through the city to the sea. The total length of the river is 393·370 kilometres (244·43 miles), and its drainage area is 16,724 square kilometres (6,455 square miles), or nearly double the drainage area of the Thames above Teddington. Plate 1, Fig. 6, shows the watershed of the river and its affluents.

---

[1] Minutes of Proceedings Inst. C.E. vols. xliii. p. 353; xlvii. p. 342; xlix p. 333; lix. p. 384; lxvii. p. 324: and lxxiii. pp. 406 and 410.

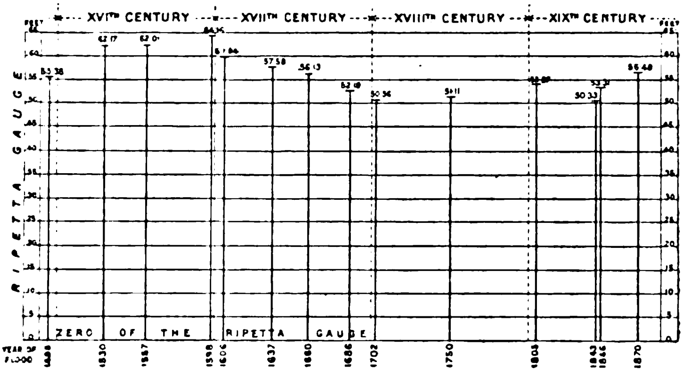
[2] "The Tiber and its Tributaries," by Strother A. Smith, M.A. 1877. p. 60.

The Floods of the Tiber.

It is certain that Rome has been subject to floods from very early times, for in the 700th year of the city (53 B.C.), a proposal was brought forward in the Senate for moderating the inundations, which resulted in the appointment of "five conservators of senatorial rank, to whom was assigned the impossible task of regulating the volume of water in the river, so that there might be no deficiency in summer and no injurious excess in winter."[1] This was probably the earliest "River Conservancy." Many inundations occurred afterwards, and in A.D. 1495 an accurate record of them was commenced. The floods of that year and of subsequent years are shown in Fig. 2.

Fig. 2.

FLOODS OF THE TIBER.



Of all the recorded floods, the highest was that of 1598, which reached 19·56 metres (64·16 feet), on the gauge at the Ripetta, or quay, in Rome, adjoining the bridge of San Angelo, and this alone is considered to have been possibly in excess of that of 1870, which reached 17·22 metres (56·49 feet) on that gauge. The level of the street at the Ripetta is 13·50 metres (44·29 feet); the depth of water in 1870 was therefore 3·72 metres (12·20 feet) on the street at that point. It was also 5 feet deep in the Corso, and covered about one-half of the inhabited area of the city.

Notwithstanding the recorded heights, there are good reasons for doubting whether the quantity of water discharged has exceeded, or is ever likely to exceed, that delivered by the flood of 1870, which has therefore been generally accepted as the standard of maximum flow. The quantity of water which then flowed through Rome has been very differently estimated by Italian engineers, whose calculations vary from 2,500 tons to upwards of 3,000 tons per second, and some think that 5,000 tons per second should be provided for. The dry-weather flow appears to be taken at 100 tons per second. The corresponding flood and dry-weather flows of the Thames at Teddington are about 465 tons per second and 27 tons per second.

---

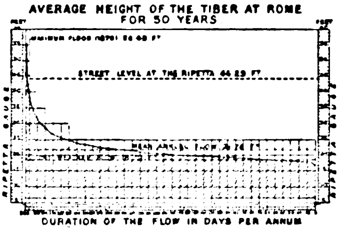
[1] "The Tiber and its Tributaries," by Strother A. Smith, M.A. 1877. p. 60.

The average flow, according to Signor Venturoli, is 283 tons per second (from observations extending over eight years), and the average annual rainfall, on the same authority, is 0·88 metre (34·65 inches).

The publications of the Hydrographic Department of the Italian Government show that, during fifty years of observation,

	Metres.	Feet.
The level of the minimum dry-weather flow at the Ripetta has been	5·20	(17·06)
The ordinary dry-weather flow was	5·70	(18·70)
The average annual flow at the Ripetta . .	6·64	(21·78)
The maximum flood (1870)	17·22	(56·49)

FIG. 3.



The water only rises above the level of the street at the Ripetta three days in the year, on an average of fifty years. This is shown in Fig. 3.

The river may be best considered in four separate divisions, namely, The Outfall, The Lower Tiber, The Urban Tiber, and The Upper Tiber.

THE OUTFALL.

The delta, which is full of interest for both the antiquary and the engineer, furnishes information by which its growth can be determined.

The town of Ostia, when founded in 633 B.C., was at the mouth of the river, was the port of Rome, and had eighty thousand inhabitants. Ostia being deprived of her port by the deposits caused by the Tiber, the Emperor Claudius, about the commencement of the Christian era, presented to the Senate a project for forming a port on the right side of the delta, 2 miles from the Ostian mouth. A basin with two moles, a breakwater, towers, and a lighthouse, were executed, and a canal to connect it with the river. It silted up, however, towards the end of the first century A.D. Trajan repaired the port, adding an internal basin of hexagonal form. The canal, which to this day forms the navigable mouth of the river, was opened about A.D. 110.

These, and many other known points—such as the towers erected close to the shore for defence at various dates—serve to mark the seaward advance of the delta, which has thus been determined by Professor Ponzi to have been 4,100 metres (2·55 miles) in two thousand five hundred years, or an average of 1·8 yard per annum.

The delta has been formed for the most part to the north-west of the river-mouth; the area of the accumulation which has taken place there since 1569 being at least double that to the south-east. This has been caused by the prevailing winds and seas, which set in from the south or thereabouts, and which drive the detritus across the river and along shore, as shown by the chart. (See Plate 1, Fig. 3, which is the French Admiralty chart, from soundings taken in 1853.)

The promontory-like delta at the mouth has served incidentally the useful purpose of protecting the entrance to the Fiumicino canal, or navigable branch of the Tiber above mentioned, from the along-shore waves, and has caused a slight eddy, the return current from which sets in a southerly direction across the small mouth. To meet this the northerly pier has been carried further out to sea than the south pier.

It is perhaps worth noting that the main flood-channel near the mouth is about the width of the Thames at the Tower of London. The depth on the bar is 1·2 metre (4 feet).

The navigable branch is 4½ kilometres (2¾ miles) in length. It varies somewhat in width. In the town of Fiumicino it measures 36 yards, and at the mouth between the piers it is narrowed to 25 yards to increase the scour. The general depth of the canal is from 3 to 6 metres (10 to 20 feet). The depth at the entrance according to the chart is 1·6 metre (5 feet 3 inches), but the Italian Government has since effected improvements there.

In dry weather there is very little difference of level between the point of bifurcation of the two branches and the sea, but in floods the water heaps up until the head is sufficient to overcome the resistance of the slack water at sea, and the sand at the mouth.

Plate 1, Fig. 2, shows the dry weather flow, and the flood of 1870, upon a longitudinal section of the bed of the river, from which it appears that the maximum fall or declivity of surface below the city of Rome occurred at the mouth, and amounted to 0·700 metre per kilometre (3·69 feet per mile).

The Author considers that the level of the flood-water line near Ostia cannot be lowered unless the obstacles to free flow are removed by an improvement of the outfall, and such an improvement would be very difficult, if not altogether impracticable, for want of sufficient water at ordinary times to maintain it. His view is confirmed by the circumstance that, in all the projects for improving the Tiber, no suggestion has been made for dealing with the main outfall.

The Lower Tiber.

Above the outfall of a non-tidal river the conditions are similar to those in tidal rivers above the influence of the tide.

The length of the valley of the Lower Tiber, measured from the railway bridge below Rome to the sea, is 26 kilometres (16¼ miles); but the length of the river from the same point to the mouth of the main channel is 37·900 kilometres (23½ miles), that is to say, there is an increased length of 45 per cent. due to sinuosities. The Author knows of no tidal valley subject to the disadvantages both to navigation and to drainage which this implies.

Mr. Possenti, an Italian engineer, proposed to shorten the existing main channel of the Lower Tiber by cutting a new course between certain points, and he calculated that this would lower the water line at Rome 0·40 to 0·50 metre (1 foot 3 inches to 1 foot 8 inches). He estimated the cost of these cuts at 3,500,000 lire (£127,000). They were abandoned for the time because that sum was considered too great a price to pay for the benefit.

It will be seen from Plate 1, Fig. 2, that the flood of 1870 had in the Lower Tiber an average fall of 0·263 metre per kilometre (1·38 foot per mile), varying from 0·184 metre (0·97 foot per mile) in the region of the greatest bends to 0·518 metre per kilometre (2·73 feet per mile) above Ostia, excluding the final fall of 0·700 metre per kilometre (3·69 feet per mile) already mentioned, as being incapable of amendment on account of the obstacles at the outfall.

Mr. Vescovali,[1] the Municipal Engineer of Rome, puts a higher value than Possenti on the straightening of the course, viz., 1·50 metre (4·92 feet), and it would seem that if the fall were equalized, so as to approach the average, the effect of the straightening would be to reduce the flood by that amount.

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[1] Giornale del Genio Civile, 1875.

THE URBAN TIBER.

This portion of the river (Plate 1, Figs. 2 and 5) extends from the railway bridge below Rome to the Ponte Milvio (or Molle) above the city, a length of 9·600 kilometres (6 miles). Here all Italian interest centres still as it has done for centuries.

Ancient Rome, mediæval Rome, and modern Rome have succeeded each other on the banks of the Tiber, and have encumbered the channel with encroachments, bridges, and ruins. Plate 1, Fig. 2, shows that the result was, in 1870, a heaping up of water in and above the city of about 3 metres (10 feet) beyond the water line of the section of the Lower Tiber, immediately below if produced at the rate of 0·298 metre per kilometre (1·57 foot per mile), which fact alone will account for the greater part of the flood.

The Italians are fully sensible of the necessity for clearing out this part of the river. Mr. Pareto reported[1] that the Government should commence by regulating the bed, and scour the bottom from the Ponte Milvio to the railway bridge, and that this alone ought to lower the flood line at the Ripetta by 2 metres (6½ feet).

The fall of water in the flood of 1870 between Ponte Milvio and the railway bridge was 5·26 metres (17·25 feet), or at the rate of 0·548 metre per kilometre (2·89 feet per mile), varying between 0·151 metre per kilometre (0·80 foot per mile) from Ponte Molle to Ponte San Angelo, where the severe constriction of the river commences, to 1·100 metre per kilometre (5·81 feet per mile) between Ponte San Angelo and Ripa Grande, the port of Rome, a distance of 3·3 kilometres (2 miles).

But even this declivity does not fully represent the torrential character of the flood, for at the bridges the inclination was much greater, and at Ponte San Angelo amounted to a difference of level between one side and the other of 0·549 metre (1 foot 10 inches). The bottom of the river at this bridge under such circumstances is scoured to a depth of 7 or 8 metres (25 feet) below its ordinary level in dry weather. The waterway is insufficient. The bridge is, however, an historic monument, having been built by the Emperor Hadrian (A.D. 136), and is supposed to have masonry inverts or sills to the arches, which have thus withstood every flood, even when submerged as in 1870.

Rise of the River-Bed.—Notwithstanding the extension of the delta, and the serpentine character of the Tiber, which in the Author's opinion would involve a rise in the bed of the river from the outfall upwards, it does not seem to be admitted as proved.

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[1] Giornale del Genio Civile, 1876.

In February, 1875, Mr. Vescovali, gave several reasons in support of it, of which the most important appeared to be that ancient Rome was notoriously lower than the modern city, and that in excavations made by him at the Via di Ripetta the ancient street was found 5 or 6 metres (18 feet) below the present level. The extension of the delta would account for 4 feet or more of this rise; and the increased bends of the river, by causing both additional length and resistance and thus reducing the velocity and creating deposits, may have occasioned a considerable further elevation.

THE RELIEF OF ROME FROM INUNDATION.

The library of the Institution contains much information on the Tiber; and as the whole of it, with one exception, bears, more or less exclusively on the mode of relieving Rome from floods, the Author does not propose to deal further than necessary with a question which is local, and which is both beyond the purpose and the limits of this Paper.

In January 1871 a Commission appointed by the Italian Government, investigated the question fully, when many suggestions were made for the improvement of the Tiber. Of these, all were disregarded which would not have been strictly local in their effect, and only two were seriously entertained, viz., those by Canevari and by Possenti.

The former was estimated at eighteen million lire (£654,500), the whole of which would have been spent on the urban length of the river, and would have added to the architectural effect of the city. The latter was estimated at eight million lire (£291,000), three and a half millions (£127,000) of which would have been spent in the straightening of the channel below Rome, already referred to. Notwithstanding the greater cost, Canevari's scheme was adopted by the Commission.

Another Commission was appointed in 1875, and had nineteen propositions laid before it, including Canevari's scheme, and an idea of General Garibaldi's, which had been worked out by several engineers as a diversion of the river by a new channel, to be cut from the mouth of the Anio, so as to skirt the city on the east, and rejoin the Tiber below.

A total diversion was shown to be open to many serious objections. Garibaldi's scheme of a total diversion, however, was modified by Mr. Amadei, so as to preserve a good channel through the city 40 metres (130 feet) in width, with walled embankments, &c., the external canal being made to convey one-seventh of the dry-weather flow and the greater part of the floods, the proportion to be discharged by each channel being regulated by a weir above the city. His estimate for the external canal and its accessories was about thirty-seven million lire (£1,345,500), which, with the internal works, made up the sum of sixty million lire (£2,182,000), the limit imposed by the Government, but his estimate was considered insufficient by the Commission.

A partial diversion was thought to give no relief equivalent to its cost. The most complete scheme of this kind, which was proposed by Mr. Baccarini, was only intended to discharge 25 per cent. of the maximum flood-volume at a cost of twenty-five million lire (£909,000) for the external canal alone, in addition to the works within the city, which were to cost another thirty-five million lire (£1,273,000). Canevari's scheme, though the estimated expense had increased from eighteen million lire (£654,500) in 1871 to thirty-two and a half million lire (£1,182,000) including the necessary accessories, in 1875, was again adopted as a basis.

The works proposed by Canevari, with modifications by Vescovali, are in course of construction.

The conclusion to be drawn from all the information collected appears inevitable, that the Italians have hitherto dealt with the improvement of the Tiber as a local Roman question. They have kept in view the double object of preventing the historic inundations of Rome and of decorating their new capital, and in so doing they have decided upon the least expensive plan which fulfils these conditions, and which confines all the expenditure to the improvement of the channel through the city.

They have had before them schemes of improvement which involve two distinct principles—one the maintenance of the existing regimen of the river and the raising of its banks; the other, the alteration of the regimen by straightening and improving the channel from the sea upwards, so as to lower the bottom; and they have, wisely in the Author's opinion under the circumstances, selected the former. This selection, however, destines the Upper Tiber to a continuance of the present floods, and to a perpetuation of the misfortunes attending "drowned lands" under cultivation.

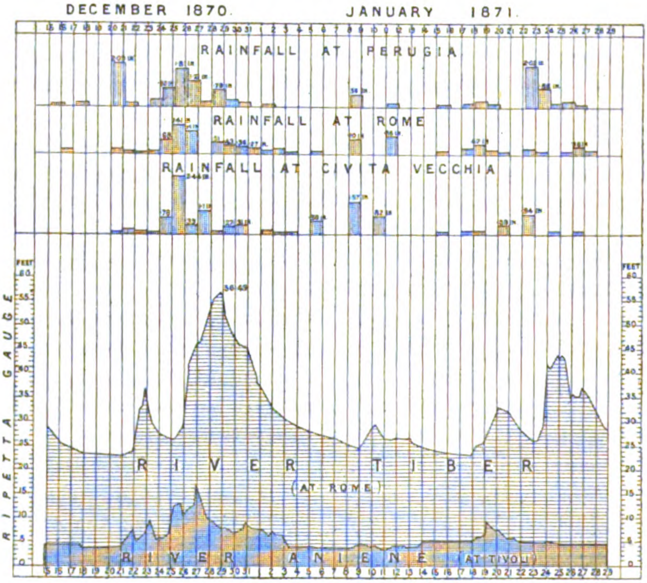
Plate 1, Fig. 8 shows General Garibaldi's scheme as modified by Mr. Amadei. Figs. 2 and 5 show Canevari's altered by Vescovali, which is now being executed. Fig. 7 shows Possenti's proposed cuts, which, however, appear to have been modified from time to time without affecting the principle. A short description of each scheme is appended to the Paper.

THE UPPER TIBER.

This section of the river includes all above the Ponte Milvio.

The valley may be described as a fertile plain as far up as Mont Orso, beyond which the country is hilly and then mountainous. The length of the plain is 40 kilometres (24·8 miles), while the length of the stream between the same points is 65 kilometres (40·3 miles), an increase of 62½ per cent. The area of the plain, which is about 100 square kilometres (38½ square miles), serves the purpose of a storage-reservoir for the equalization of the floods before they reach Rome.

FIG. 4.



The serpentine windings of the river considerably retard the water, and it is further dammed back by the Ponte Milvio which was submerged in 1870, so that the first flood-stream thus set in from the upper side of this bridge towards the city, and entered it at the Porta del Popolo.

For every 2 metres (6½ feet) depth of water on the plain, 200 million tons of water would be stored, equal to a flow of eighteen hours at 3,000 tons per second; and, assuming the velocity in the river at 2 metres per second (6½ feet), the retardation due to the bends would be equal to another three and a half hours, making a total delay of twenty-one and a half hours in the descent of the flood upon Rome. When it is considered that the overflow of the river within the city lasts only three days, the value of the plain as a reservoir is obvious.

On the other hand, the injury caused to the farms of the Campagna, or plain, by the deposit of mud, which is not immediately fertile, and the destruction of crops, is very great. Supposing it to be commercially practicable to straighten the river, it would be necessary first to determine the effect of discharging the water more rapidly and uniformly upon Rome instead of allowing it to accumulate above it.

Fig. 4 gives some interesting details of the rainfall over the watershed of the Tiber, which caused the flood of 1870, and the corresponding flow of the Tiber and Aniene, from which it appears that the flood of the latter river passed before the greater flood arrived—a fact of considerable importance in any proposed rectification of the channel.

In connection with the Upper Tiber, it should be mentioned that the most interesting and elaborate Report, with plans and sections, made by the Italian engineers Chiesa and Gamberini, in 1746, is in the library of the Institution. It represents the whole river from Orte to the sea, and so far as concerns the Upper Tiber, the Author believes it is still unsurpassed.

Among the proposals for abating the floods in Rome was the construction of storage-reservoirs on the Upper Tiber and its tributaries; but Italian engineers are not generally favourable to this plan, and French experience on the Loire is pointed to in support of their view, chiefly on the ground of the cost being disproportionate to the benefits likely to be obtained.

In conclusion, the Author doubts whether the principle of improvement of tidal rivers, adopted by English engineers, viz., "carrying low-water at sea as far inland as possible," is applicable to rivers flowing into tideless seas. The difficulty at the outfall seems to be very great, if not insuperable, and where the lower sections of large rivers are dealt with, the advantage to be gained by straightening the course of the stream appears so small in comparison with its cost as to be inadmissible.

In small rivers, or in the upper valleys of large rivers, such a rectification would be practicable, as the fall would be greater and the cost less, but it would accelerate the descent, and thus increase the volume, of the floods in their passage through any given section below.

By contrast with straightening and lowering the water-line, the embanking of the channel, where large volumes of water have to be dealt with, is doubtless the most economical and efficient plan for the localities aggrieved by floods, without reference to the general well-being of all the interests on the river. The effect, however, of such embankments without improving the cross-section would be to raise abnormally the height of the flood, to diminish its velocity in the region above, and to increase the velocity below—conditions which tend to form shoals, and to raise the bed of the river much beyond what is due to the extension of its delta, and to injure its efficiency for drainage.

Lastly, whilst the Author is convinced that every river should be separately studied, he ventures to hope that the subject of this Paper may be suggestive in relation to that part of English rivers which most needs attention at present, namely, their non-tidal sections.

The Paper is accompanied by numerous diagrams from which Plate 1 and the Figs. in the text have been engraved.

APPENDICES.

APPENDIX I.

CANEVARI'S SCHEME, AS ADOPTED BY THE COMMISSIONERS OF 1871 AND 1875.

This project consists in:—

1st. The removal of all obstacles to the free flow of the river through Rome, and the regulation of the bed and banks.

2nd. Collection of the sewers of the city into a sewer able to discharge into the Tiber, so far below Rome that the reflux of the maximum flood should not rise into the city.

3rd. Embankment in masonry of the urban channel of the Tiber to a height which should leave a freeboard above the maximum flood-level, and embankment beyond Rome to prevent the water from the higher reaches entering the city.

Estimate.

	Lire.	£.
Land	7,376,000	268,220
Earthwork in the channel	3,002,000	109,170
Embankment walls with outfall sewers	15,593,000	567,020
Parapets	345,000	12,550
Embankment, &c., in quays	1,310,000	47,640
Paving ditto	1,495,000	54,370
Connecting up the sewerage	128,000	4,660
" " streets	397,000	14,440
Gravelling	37,500	1,370
Accessory works	2,805,000	102,000
	32,488,500	1,181,440

Canevari considered at first that his works would reduce the level of the 1870 flood to 14 metres (46 feet) at the Ripetta.

The Commission of 1875 concluded that the clearing of the bed of the river through the city would reduce the flood-level of 1870 from 17·22 metres (56½ feet) to 16·14 metres (52 feet), and that the level of the proposed embankments should be 17 metres (56 feet) at the Ripetta, with an extra freeboard of 1·20 metre (4 feet) given by the parapets.

They considered it necessary that the bottom of the river at the Ponte Milvio should not be altered; that the walled embankments should be constructed without the counterforts shown on the drawings; that in front of them low-level quays or towing-paths should be made for navigation, so as to keep the dry-weather flow in a smaller channel, and that these quays should be 8 metres (26 feet) wide, and 0·20 metre (8 inches) above the ordinary flow of the improved river; that the width of the improved river should be 100 metres (328 feet) between the footings of the walls; that two new arches should be made to the Ponte San Angelo, and that the bed of the river within Rome should be completely excavated for its whole width to a regular fall of 0·40 per 1,000 (25 inches per mile), starting from 1·50 metre (4·92 feet) at the Ripetta, and falling to zero at Porta Portese (Ripa Grande).

APPENDIX II.

GENERAL GARIBALDI'S SCHEME, AS DEVELOPED BY AMADEI.

The object is to show a scheme for giving a flow of 120 tons per second in dry weather, and 200 tons per second in ordinary flow in the urban channel, and to carry off the water exceeding this flow in an external canal, maintaining a dry-weather flow in the latter of 20 tons per second, which would be necessary for the public health.

The works proposed comprise:—

1. Works not included in the external canal and the urban channel.

A dam 500 metres (547 yards) above the mouth of the Aniene, to allow, in time of drought, a flow of 20 tons per second in the external canal, and to cause the rest to run into the urban channel.

A structure, with seven arches and sluices, to provide for inland navigation. In this a sluice near the acute angle of the dam, to allow, when desirable, part of the water of the urban channel to flow into the external canal.

Systemization of the bed of the Tiber, from the dam to the Serpentara.

A strong embankment from the Tor di Quinto to the Ponte Salario, 2,700 metres (8,858 feet) in length, and of a height to give a margin of 2·60 metres (8·53 feet) above the maximum flood-level.

2. External canal.

This would commence immediately below the dam, in a right line with the reach of the existing river above it. Passing up the valley of the Aniene round the city, as shown on the plan, it would continue its course so as to leave the Basilica on the left, and would run down the valley of the Tiber by an independent channel to the Fosso di Malafede, when it would discharge into the existing channel of the Lower Tiber. The bottom from the foot of the dam would have a fall of 0·304 per 1,000 following the line of bottom of the upper reach of the Tiber. The width would be 30 metres (98 feet), and the banks would have a slope of 1½ to 1, with benches 3 metres (10 feet) wide, at every tenth metre in height. The width of the bottom should not be much more nor less than 30 metres (98 feet).

In droughts the channel is intended to receive first 20 tons of water per second from the sluice of the dam, then the flow of the Aniene, and lastly 10 tons from other affluents; in all, 50 tons per second. If the channel should be made narrower than 30 metres (98 feet), in time of flood the water would be dammed back to an extent that would affect the regimen of the Tiber. If wider than 30 metres (98 feet), water from the sluice would flow, in time of drought, with a depth less than 0·77 metre (2·52 feet), and with a less velocity than 0·82 metre (2·69 feet) per second, and deposits of mud would occur.

At the outfall the bottom should have a level of 0·70 metre (2·29 feet), that is 0·50 metre (1·64 foot) below the water-level of the Tiber in time of drought, and the canal, when full, would have a capacity equal to a flow of 347·77 tons, with a velocity of 1·79 metre (5·87 feet) per second.

The internal surface of the embankment would be carried to a height of 20 metres (65 feet) above the bottom of the canal, with a slope of 2 to 1.

Giving the margins between the channel and the banks a width of 30 metres each (98 feet), a flood could flow in the whole section equal to 5,100 tons per second, with 2·94 metres (9·64 feet) per second velocity, leaving a freeboard of 1·88 metre (6·17 feet) sufficient to accommodate even the flood of 1598. The external channel would require ten iron bridges.

3. Urban channel of the Tiber.

This would commence at the proposed dam, and would follow the present bed, dredged and rectified. Its length to the Fosso di Malafede would be 24,500 metres (15¼ miles). Its level at the commencement would be 8·414 metres (27·60 feet), and at the outfall of the external canal, with which it coincides, 0·700 metre (2·29 feet), whence the mean fall is 0·344 per 1,000. The bottom of this canal in the city should have a width of 40 metres (131 feet). The water, in time of droughts, should flow at 120 tons per second, with a depth of 2·30 metres (7·54 feet), and a velocity of 1·34 metre (4·40 feet) per second. With the ordinary flow of 200 tons per second there would be a depth of 3 metres (9·84 feet), and a velocity of 1·54 metre (5·05 feet) per second.

A second dam (shown on the plan) could be made below the first, if any fear of damage from the failure of the latter should be entertained.

Estimate.

	Lire.	£.
1. Works besides canals	3,218,234	117,027
2. External canal	33,867,806	1,231,556
3. Urban channel of the Tiber. . . .	17,626,590	640,967
	Lire 54,712,630	£1,989,550
Which, with contingencies, &c., is made up to	,, 60,000,000 =	£2,181,818

APPENDIX III.

Possenti's Scheme, brought before the Commissioners of 1871 and 1875.

This project consisted in a proposed lowering of the flood-level of 1870 at the Ripetta, as follows:—

	Metres.	Feet.
By cleansing the bed of the river.	1·80	5·90
,, enlarging the cross-section.	1·00	3·28
,, improving the bridges	0·60	1·97
,, straightening the course of the river below Rome	0·40	1·31
Total . .	3·80	12·46

Possenti proposed to secure the bottom of the river at the Ponte Molle by a weir, which would limit the scour of the bed to the river below that point, and to construct banks on each side of the river above Ponte Molle, to contain the water which is dammed back by that bridge.

He estimated the total cost of the works at 8,000,000 lire (£291,000), of which 3,500,000 lire (£127,000) would be spent upon the straightening of the river below Rome.

[Discussion.

Discussion.

Mr. Shelford. Mr. W. SHELFORD said there were one or two points to which he should like to refer before the discussion commenced. A friend who had heard that he was about to read a Paper on Non-tidal Rivers, made the remark that fortunately there were not many of them. He appeared to have forgotten that most of the great rivers of the world ran into tideless seas. In Europe, the Volga ran into the Caspian, and the Danube into the Black Sea; in Africa the Nile ran into the Mediterranean; in Asia little was known about the rivers, but some of them certainly ran into the Black Sea and the Caspian; in America the Mississippi, the largest river in that continent, ran into the Gulf of Mexico. But the striking circumstance was that, where ports and large harbours existed in tideless seas, they were carefully put at a distance from the rivers. Marseilles, for instance, a most important port, was some miles from the mouth of the River Rhone, and had thus been cut off from the advantages of the inland navigation. In the case of a tidal river, Marseilles would unquestionably have been on the river itself, or at the mouth. That, he supposed, had arisen from the experience of Rome, the old Romans having, at the beginning of the present era, had a port called Ostia at the mouth of the Tiber, and because it was silted up, and became inaccessible, it was shifted by Claudius to Fiumicino, a distance of 2 miles. The present port of Rome was Civita Vecchia, still further north; it was approached by railway, the navigation of the Tiber being practically *nil*. The diagrams which he had exhibited very inadequately represented the plans and sections from which they were made. Those plans and sections were prepared for the Italian Government by the Commission of 1871, and they were presented to him by the late Mr. Cialdi, of Rome. The Italian engineers and hydraulicians whom he had mentioned were consulted by the Italian Government at the time when the disastrous inundation of 1870 occurred, and might therefore be considered as authorities on the subject. One person whom he had not included in the category was Mr. Vescovali, the present Municipal Engineer of Rome, who had modified Canevari's scheme, and Plate 1, Fig. 5, showed the works which were now being carried out under that modified scheme, prepared from information furnished to him by Mr. Vescovali. The cost of the work already executed, and of the property purchased, had been £1,100,000, and the Italian Parliament was to be asked during the present year for

£2,000,000 more for the purpose of completing the work. Although Mr. Vescovali was concerned in the works, he at first energetically opposed the idea, looking upon the embanking of the Tiber with ornamental walls, like the Thames Embankment, as a palliative rather than a cure, and he had always advocated the straightening of the Tiber below Rome. He did not propose to effect any improvements lower than the point called Ponte Galera, which was the summit of the extremely sharp fall of the flood of 1870. He therefore assumed that, like every other engineer, he had been afraid to attack the outfall. He believed this was the first time that the outfalls of non-tidal rivers had been referred to at the Institution at any length, and he hoped the Paper would prove a useful one. Mr. Shelford.

Sir Charles Hartley.

Sir CHARLES HARTLEY, K.C.M.G., stated that the navigable depth of the channel of the South Pass of the River Mississippi, the opening of which, in preference to the South-West or to either of the South-East passes, he was the first to advocate,[1] from deep water in the main river above the head of the pass to the gulf, was 26 feet, and the width from 240 to 300 feet. Soundings, however, could be taken from one point to the other, giving a depth of at least 29 feet in the Pass itself, and through the jetties of over 30 feet. In the same way at the Sulina mouth of the Danube there was now a depth between deep water in the river and deep water in the sea of 20 feet 6 inches over a navigable channel 300 feet wide, but soundings could be taken between those two points of something over 24 feet. It could not be said, however, that the depth of the South Pass was 30 feet, or that at Sulina the depth was 24 feet, for in both cases the width of channel at these respective depths was insufficient for the navigation. He considered it to be a great triumph for Mr. Eads, considering the difficulties he has had to contend with, that last year seven vessels left the Mississippi with a draught of more than 24 feet, and one of them with a draught of 25 feet 10 inches.

With respect to great rivers entering tideless seas, it should be remembered that some non-tidal rivers were comparatively easily dealt with, while others were impracticable. Exposed outlets like the mouths of the Mississippi and the Danube, and outlets like those of the Pregel and the Oder, which before reaching the open sea entered into Haffs or Lagoons, which served as settling basins, might and had been successfully improved; but on the other hand he thought that the improvement of the mouths of

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[1] See "Mouths of the Mississippi Correspondence, etc. Clowes & Sons, 1875," in the Library of the Institution.

Sir Charles Hartley. such rivers as the Volga and the Don was almost impracticable, because the slopes opposite those mouths were extremely flat; the littoral current was almost imperceptible, and the direction of the wind unfavourable to successful treatment. Similar allegations might be made with regard to many tidal rivers entering tidal seas. The river Adour, for example, had hitherto been unamenable to improvement, and the Hooghly would be very difficult to improve, whereas the Thames below London Bridge, and the Scheldt below Antwerp, for the time being at least, needed no serious improvement, and the same thing might be said with regard to other rivers. It would occupy too much time to discuss the relative advantages and disadvantages of tidal and tideless rivers, from an engineering point of view, but it was clear that in both cases the chief aim should be to carry deep water as far up stream as possible, in such a manner as to perpetuate, without undue cost or onerous maintenance, the retention of any increased depth that might once be obtained by artificial means.

With regard to the Tiber, he had had an opportunity of visiting the delta of that river both before and after the flood of 1870, and therefore took a great interest in the question of its improvement, although he knew nothing as to the merits of the plans which had been proposed. It had been stated that nineteen projects had been submitted, and it would therefore be very rash in him to express a definite opinion as to the best mode of carrying out so great an improvement. No doubt the works in progress, part of which he had seen in December last, would give great relief to the floods at a comparatively small cost, but he was not sure that the wisest course had been adopted. Garibaldi's scheme for a diversion of the river outside the walls of Rome, as amended by other engineers, was a much grander one, but the cost would have been much greater, and, as in all such cases, the chief question to be considered was whether the game was worth the candle?

He wished to ask a question with reference to the zero shown on the longitudinal section of the bottom of the river. When he was in Rome he was told that the zero at the Ripetta gauge indicated a level of 1 metre and 17 decimals, about 4 feet, above the level of the sea, and that all the references on the gauge related to that zero, and not to the height above the level of the sea. Consequently the great flood of 1870, which was marked in the Paper at 56·49 feet, should be 60·49 feet. In ordinary dry weather the flow in that case would be 23 feet, and the minimum dry-weather flow would be 21 feet, instead of 17 feet above sea-level.

With reference to the proportion of dry-weather to flood-flows, Sir Charles Hartley.

the maximum appeared to be 1 to 30, which was not very great in comparison with the enormous difference in some other rivers. In the river Ruhr, which flowed into the Rhine, the proportion was 1 to 300; at the mouth of the Durance, before entering the Rhone at Avignon, 1 to 170; and at the mouth of the Rhone itself 1 to 22. The proportion given by Vescovali of dry-weather to the mean flow was large, 1 to 3; in the case of the Danube and the Mississippi it was about 1 to 5; of the Po 1 to 8, if he was correctly informed; so that the larger proportion in the case of the Tiber was, he thought, a favourable element with regard to the improvement of its outfall.

As to the advance of the delta, the Author had given an average of 1·8 yard per annum, so that, taking the time as two thousand five hundred years, the distance was 2½ miles. The advance of deltas, however, was very uncertain; sometimes they were almost stationary, or were even encroached upon by the sea for periods of long duration, at other times they advanced rapidly, and at others slowly. He had visited the mouth of the Fiumara, the large mouth of the Tiber precisely three hundred years after the erection of the tower, St. Michael's, which was built on the seashore in 1569. In 1869 it was 5,520 feet from the sea, giving an average advance of 18½ feet per annum in the direction of the main channel. He believed it had been ascertained that the present advance of the delta between the two mouths was at the rate of 12½ feet per annum. Opposite the Sulina mouth of the Danube and the mouth of the South Pass of the Mississippi the deltas had advanced from 60 to 100 feet annually, whilst the rate of advance of the sandbanks opposite the mouths of the Kilia and St. George's Mouth in the one case, and the South-West and Pass à l'Outre and South-East Mouths in the other case, was more than three times greater than at the outfalls of the improved branches. The most salient angle of the Po and that of the Rhone was advancing at the rate of 220 and 190 feet per year respectively. Compared with these examples, the advance of the delta of the Tiber was very small.

Regarding the slope of the bottom of the Tiber, opposite the Fiumara mouth, and also opposite the Fiumicino mouth, measuring on the Admiralty chart, which was taken from the French chart, he found that at a distance of ¾ mile from the shore the depth was 30 feet. That also was a favourable element in considering the improvement of the outfall of the Tiber. At Sulina at the same distance from the shore, the depth was only 18 feet before the jetties were constructed. The Author had stated that

Sir Charles Hartley. there was an increased length in the river below Rome of 45 per cent., owing to its sinuosities, and that he knew of no tidal valley subject to the disadvantages both of navigation and drainage which that implied. But the length of the Seine between Rouen and the estuary was about twice the distance in a straight line.

He fully agreed with the Author that in river-engineering the fundamental conditions to be studied were at the outfall, but he could not concur in the opinion that with regard to the Tiber the improvement of its outfall would be very difficult, if not impracticable, for want of sufficient water at ordinary times to keep it clear. On the contrary, remembering the advantages of a comparatively steep slope in front of the mouths, the slow advance of the delta, and observing the direction of the currents, and the comparatively large proportion of the dry-weather flow to the mean flow, he thought that the improvement of the outfall, and the regulation of the lower part of the river would not be very difficult or beyond the ordinary skill of the engineer.

It was of course absolutely necessary to consider the relief of Rome from the floods, which did an enormous amount of damage, principally owing to the great amount of silt deposited by them. He visited the Pantheon, for instance, after the subsidence of the flood of 1870, and on going there, partly in a boat, he got ankle deep in mud deposited by the river. He should have liked to hear something about the amount of mud held in suspension, and also about the velocities of the current at the time of the flood and at ordinary times.

There was, however, something else to consider of great importance beyond the question of floods, namely, the provision of a Seaport, either at the mouth or higher up the river, that should be worthy of the eternal city, replacing the present maritime port of Civita Vecchia, which was merely an open roadstead 50 miles from Rome. He was rather surprised, seeing that nineteen projects had been made for the urban part of Rome, that no project had been submitted for improving the lower part of the river, with the view not only of protecting the city from floods but of restoring the Tiber to its ancient function as the great maritime approach to the capital of Italy.

Mr. Maudslay. Mr. Henry Maudslay said he witnessed the extraordinary flood at Rome in 1870. The annoyance and distress arising from it were very great. There were no boats, and he was hard at work near the Ponte San Angelo making rafts. The only means of getting about in the lower parts of the city was by these rafts, which were formed of doors, or the bodies of wagons placed upon empty barrels. In this way food and medical necessaries were supplied from house to house. The principal obstruction to the flow of the water was the long continuance of the wind in one direction. The winds which increased the bar at the mouth of the Tiber were from the north-west or south-east. Where a river, such as the Tiber, flowed into a tideless sea, a delta was formed which increased to such an extent that the water could not get out. When the waters came rushing down from the Apennines, so great was the flow that fears were entertained that the Ponte San Angelo, which was the first obstruction, would be blown up, cutting off communication between one side of the city and the other, until the subsidence of the water, which covered the approach to the bridge during a day or two to a depth of 15 feet, while the depth at the Ghetto was 30 feet. It was hardly likely that the lower portion of the river could be made navigable unless some new outfall were cut, because in the present condition of the Tiber, the delta would be constantly extending. The Tiber was not tidal; therefore, to prevent inundations, all the obstructions ought to be removed, such as the piers of the old bridge below Ponte San Angelo. In floods the water flowed back into the city by the Cloacas, or main drains, up through the fountains and gully-holes, with all the accumulated filth, thus producing fever, misery, and death. Mr. Maudslay.

Mr. Airy. Mr. WILFRID AIRY wished to say a few words in explanation of the formula mentioned in the Paper in connection with his name. One or two numerical examples of the meaning of the formula might be given. Taking the case of a stream moving with a velocity of 8 feet per second, that velocity being increased to 9 feet in consequence of artificial works or flood, the formula showed that the increased velocity would move particles of silt of double the weight that it would before. Again, if by any means the velocity of a current could be doubled it would move particles of silt of sixty-four times the weight that it did before, showing the enormous effect of a small increase in the velocity of a stream in removing silt from its bed, or from a bar at its mouth. The formula was an extremely simple one, derived from simple considerations, treated in their simplest and approximate form, but taken as a guide he thought it was quite reliable. The proof was as followed:—

Let V = the velocity of a current,
and a = the length of the edge of the largest cube which the current could move.

Mr. Airy. Then, weight of cube $= m\,a^3$ (m const.),
and, friction of cube on bed of river $= p.m.a^3$ (p const.),
also, total pressure of current on face of cube $= q.V^2.a^2$ (q const.).

For equilibrium

$$p.m.a^3 = q.V^2.a^2,$$

$$\text{or} \qquad a = \frac{q}{p.m.} \cdot V^2.$$

Therefore the weight of the largest cube that a current with velocity V could move was $m\,a^3 = \frac{q^3}{p^3.m^2} \cdot V^6$.

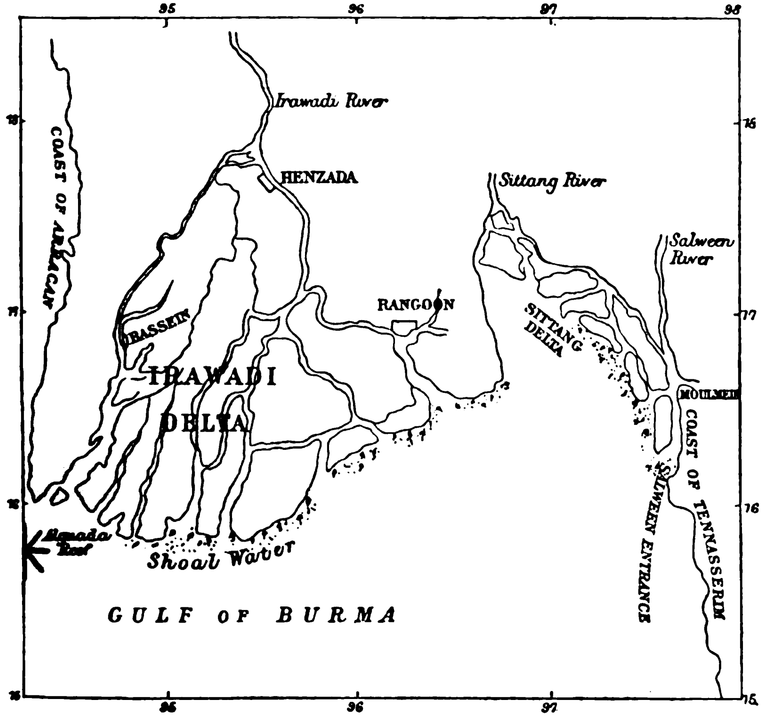
And if W W′ were the weights of cubes of silt, &c., that could just be moved by the velocities of current V V′ respectively, then $\frac{W}{W'} = \frac{V^6}{V'^6}$.

Cor. I. If the velocity of a current was increased by $\frac{1}{8}$ part, it would move particles of twice the weight, for $\frac{1^6}{(1{\cdot}125)^6} = \frac{1}{2}$ nearly.

Cor. II. If the velocity of a current was doubled it would move particles of sixty-four times the weight, for $\frac{1^6}{2^6} = \frac{1}{64}$.

Mr. Gordon. Mr. Robert Gordon said Fig. 5 illustrated the formation of deltas in a tidal sea at the north-east corner of the Bay of Bengal. The gulf was formed by the continuation of a mountain chain running underneath the sea, and secluding it from the rest of the bay. Within that region the tide rose and fell, and there were great sea currents. In that small space, about 220 miles wide, there came down three large rivers, two of them ranking amongst the greatest rivers in the world. The Salween had a drainage area of 500,000 square miles, and a course of 3,000 or 4,000 miles. The Sittang had a drainage area of 20,000 miles, and only a short course. The Irawadi had a disputed area of from 200,000 to 400,000 square miles. The Salween discharged 500,000 cubic feet per second in flood. He did not know the amount discharged by the Sittang. The Irawadi discharged as much as 2,000,000 cubic feet per second in high flood. The Salween had no delta, and no estuary. He did not know the rise and fall of the tide, but it was considerable, perhaps nearly 20 feet. The Sittang had a negative delta, the sea rushing in and out, and the whole area usually occupied by the delta being hollow. A series of islands was formed on the eastern side, and no ship or boat could go in, as an enormous bore existed there. The Irawadi also offered curious examples of delta formation. The main body of the water came down in the interior channels, but all those channels had the phenomena which the Author had ascribed to non-tidal rivers. There was a rise and fall of tide of 19 feet at Rangoon, 30 miles up the Rangoon river. On the other side there was another branch, the Bassein River, an estuary of the sea, where the rise and fall of the tide was 10 feet 90 miles up, but in all the other channels, although the tide flowed in and out in dry seasons, no navigation from the sea was possible. There were bars with only a few feet of water over them, and the water overpowered the sea-tides in flood. The delta continued to project into the ocean, and formed a shallow in front of it in the bay. **Mr. Gordon.**

FIG. 5.


95
96
97
98
Irawadi River
HENZADA
Sittang River
Salween River
COAST OF ARRACAN
BASSEIN
IRAWADI DELTA
RANGOON
SITTANG DELTA
MOULMEIN
COAST OF TENNASSERIM
SALWEEN ENTRANCE
Alguada Reef
Shoal Water
GULF OF BURMA
17
16
15
95
96
97

With reference to Mr. Airy's formula, he might mention that he had experimented on the discharge of the Irawadi for several years.

Mr. Gordon. During 1877 he took the minimum discharge and the greatest flood ever recorded, the measurement being continuous for three hundred and sixty-five days. He measured the quantity of silt carried at the surface, near the bottom, and at mid-depth in the centre of the stream, and the results could certainly not be expressed by Mr. Airy's formula, or anything like it. The river had a rise and fall of about 44 feet at the head of the delta, just where it bifurcated. During the dry weather, when a volume of from 50,000 to 100,000 cubic feet of water was flowing, and the velocity was from 1 foot to 2 feet per second, the mean ratio of the three measurements was 22 parts of silt in 100,000 parts of water by weight. During the greatest flood it was 104 in 100,000 by weight, the difference being as 1 to 5, very nearly in the first power of the velocities, taking from 1 foot to 2 feet per second in dry weather, and from 6 to 8 feet per second as the mean velocity in floods from the surface to the bottom. The amount of silt at the surface, and at mid-depth was very much the same, but near the bottom it was from three to five times greater, and the extreme variation was from 1 part in 100,000 at about 100,000 feet discharge, and 2 feet per second, to 304 parts in 100,000 by weight at very highest flood, which was something less than the cube of the velocities. These measurements agreed very fairly with those of the Mississippi, and of other great rivers in different parts of the world. He did not know what correspondence Mr. Airy's formula had with actual fact; but with the above range of velocities of from 1 foot to 8 feet per second, the eroding and removing force would by the formula vary from 1 to 250,000, instead of 1 to 300. There could be no doubt that the amount of silt carried by the river was a measure of the erosive power of the water itself, for the silt was being constantly deposited and constantly re-excavated from the banks. If the current ceased to excavate, the whole of the silt would be deposited in a short distance, except the very fine silt mechanically held, and that in chemical solution.

The Author had mentioned that there were two methods of improving a river, one by embanking, and the other by straightening and lowering the surface; but the Americans were using another method in the case of the Mississippi, depending on the erosive action to which he had referred. They curtailed the erosive action by lining the banks of the river at the parts where the erosion was the greatest; they therefore, by reducing the eroding action, retained the force of the water, increased the velocity of the current, and thus reduced the cross-section required to carry a certain amount of water. In that way they hoped to make the embanking less. They had carried on this work for some years. He went over 25 miles of this last summer near St. Louis, with Major Ernst, the officer in charge, and they had certainly been very successful. The lining consisted of matting woven in continuous lengths on barges anchored at the spot, and moved down stream as the mattress was deposited. In one case a mattress, over 4,000 feet in length, and from 120 to 300 feet in width, was applied. The banks were shaped, where required, by the hydraulic jet, and rows of piles were driven to secure the mats. Mr. Gordon.

Mr. Law. Mr. HENRY LAW thought the point in the Paper of greatest interest, especially at the present moment when such questions were much discussed in reference to the Manchester Ship Canal, was that of the ratio existing between the force and the velocity of running water in regard to the scour. The Author had stated, on the authority of Mr. Airy, that the capability of a stream for moving detritus was as the sixth power of the velocity, and Mr. Airy had given a demonstration of that statement in which he had assumed the particle to be a cube sliding along the bed of the river. Mr. Law had subsequently looked into the matter, and had found that the formula would be equally true if, instead of assuming the cube to slide, it was assumed to be rolled over, which was the more likely mode of progression, and also if the particle was either a cube or a sphere. Adopting Mr. Airy's notation, there was for the moment of resistance to the cube being turned over upon its edge—

$$\frac{m\,a^4}{2},$$

and for the moment of the force of the current tending to turn over the cube

$$\frac{q\,V^2\,a^3}{2},$$

and as the cube was on the point of turning, these must be in equilibrium, and

$$\frac{m\,a^4}{2} = \frac{q\,V^2\,a^3}{2},$$

and by reduction

$$a = \frac{q}{m}\,V^2.$$

Again, assuming the particles to be spheres, instead of cubes, and that a particle was resting upon three other particles; in

Mr. Law. that case, putting d for the diameter of the sphere, there was for its weight

$$\frac{m \, \pi \, d^3}{6}.$$

And if $\frac{d \sin \beta}{2}$ was the horizontal distance of the centre of the sphere from the point of contact about which it had to be turned, there was for the moment of resistance to turning

$$\frac{m \, \pi \sin \beta}{12} d^4.$$

Then the pressure of the current would be

$$\frac{q \, \pi \, d^2 \, V^2}{2},$$

and the moment tending to roll the sphere onward would be

$$\frac{q \, \pi \, d^3 \cos \beta \, V^2}{4},$$

and when the sphere was on the point of moving

$$\frac{m \, \pi \sin \beta \, d^4}{12} = \frac{q \, \pi \cos \beta \, V^2 \, d^3}{4},$$

and by reduction

$$d = \frac{3 \, q \cot \beta \, V^2}{m}.$$

Then, as q, m, and β were constant, and the weights of the particles were as the cubes of a and d respectively, it followed that, whether the particles were cubes or spheres, the weight of the particles which the current would be capable of rolling onward would vary as the sixth power of the velocity of the current. That was a startling proposition, but no doubt it was true where the material of the bed of the river was perfectly clean sand or gravel free from all cohesion. When cohesion came into play, as in the case of binding gravel, clay, marl, or rock, the law no longer held good, and then the power of the stream to tear up the bed would be as the square of the velocity. But in that case the depth also must be taken into account, because if a particle of the bed was considered as adhering to the bed, and a rounded surface projecting above, which the water attacked, a particle of water striking that sloping surface would of course be thrown off according to the usual law of deflection. If the water was very shallow, there would be very little resistance to that particle so being deflected, and it would not produce the same

Mr. Law. amount of work upon the particle cohering to the bed of the river as if the column of water upon it was higher. That, therefore, would account for what was seen in practice—that the scouring power of a very shallow stream running at a very high velocity, was far less than the scouring power of a deeper river running with a smaller velocity. If it was assumed that the particle of water which struck the projection in the bed of the river had not its weight increased as far as its *vis viva* was concerned, but had it increased in consequence of its being held down by the column of water above it, then it would be seen that in striking the particle it produced so much more force, because it could not glance off readily, but was held down and compelled to do its work. The law, however, enunciated in the Paper would have to be modified in the case of bars of estuaries; it applied only in what might be called quiet streams, where there was no other motion than that of the current itself. Under the motion of the waves, the depth came into play, because there was a horizontal motion on the bed of the sea in every case where the depth was not greater than the horizontal distance between the crests of two waves. Where the depth was less than that distance, there would always be a motion backwards and forwards, answering to that of the waves, which would alternately accelerate and diminish the velocity of the current itself, and would affect its efforts in breaking up the bed of the river.

Mr. Thelwall. Mr. W. H. Thelwall, referring to the expression "tideless," said that the Mediterranean was not a tideless sea, though of course its tides were very small. He should be glad if the Author would state what the tides were at the mouth of the Tiber. On the other side of Italy, in the Adriatic, the spring-tides were about 2 feet 6 inches, and in Venice the mean range throughout the year was 1 foot 11 inches; the range of spring-tides 2 feet 6 inches; and the maximum range from the lowest ebb to the highest flood was as much as 8 feet 6 inches. At the mouth of the Po, where he imagined the delta was of the same kind as that of the Tiber, the tidal wave passed up the river to a distance from the mouth of nearly 80 miles, and that must have a very considerable effect upon the formation of the delta. He did not quite understand the distinction drawn by the Author between deltas in tidal and in non-tidal seas. One of the principal deltas in the world was that of the Ganges, in which the extreme range of the tides was about 17 feet. The Author's statement in regard to tidal reservoirs did not apply to the Ganges. When the river was low the water passed up the stream to a distance of 200 miles. In flood

Mr. Thelwall. times, when the volume of water in the river was very great, the tidal action was hardly felt, the water brought down by the flood being so enormously in excess of that taken up by the tide. The question of the volume of water discharged by the Tiber was a very interesting one, and seemed to have greatly puzzled the Italian engineers, because, as shown by the Author, the difference between the lowest and the highest calculations for the maximum flood in 1870 was 100 per cent., and even when the river was much lower the differences were very great. At low water, when the height by the Ripetta gauge was 5·30 metres, the lowest calculation gave a flow of 95 tons per second, and the highest 190 tons; but again, when the river was in slight flood with a height of 8 metres, the lowest calculation out of seven or eight gave 450 tons per second, and the highest 665 tons. Italian engineers had adopted various methods of determining the velocity by the use of current-meters, floats, and other means; but they all seemed to differ in their results. He would be glad if the Author would state what had been taken by the Italian engineers as the actual volume to be provided for in the new works upon the Tiber. The matter was of course one of great importance, because if the lowest calculation was taken the works might be much too small, and if the highest they might be much too large.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT did not think that Englishmen could take the credit of having done all the tidal-river improvement in the world. The improvements of the Seine and the Maas were well-known instances of foreign works, and ought not to be left out of account. The Author had stated that non-tidal rivers had not very often been improved. The general reason for that was, he thought, that the difficulties in improving them would have involved works that had not been deemed worth the expense. In tidal rivers there was a ready means of access from the sea into the interior of the country which tideless rivers did not afford. That was one of the reasons why it was found in the case of tideless seas that ports were not upon rivers, to which the Author adverted after the reading of the Paper, but were generally, as in the case of Marseilles, Algiers, and Alexandria, on the sea-coast. The Author had referred to the formation of deltas, as peculiar to non-tidal rivers, and Mr. Thelwall had alluded to the Ganges as a case of a tidal river forming a delta, but he had plainly indicated how that delta was formed. When the river was in flood it overpowered the tide. That was the time when it formed its delta, and it was then that it was practically a non-tidal river. There were also cases of

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non-tidal rivers not flowing into what were generally understood to be tideless seas. There was the well-known case of the Mississippi flowing into the Gulf of Mexico, which was open to the Atlantic. There was also another case, perhaps more remarkable but not so generally known, that of the Paranà river flowing into the estuary of the La Plata, and from thence into the Atlantic Ocean. It practically formed a delta within the estuary of the La Plata, because there, owing to a confluence of tides, there was very little tidal range. So that on the Atlantic itself there was an instance of a practically non-tidal river outfall. In the case of tidal rivers there was a constant ebb and flow, and therefore almost a constant motion of particles in suspension. Slack water was the time when deposit took place, and that occurred not at one place only, but at several places, according to the state of the tide, and it varied not only at different hours of the day but in different localities, and according to whether it was spring or neap tide. In the case of tidal rivers also, a considerable fall was developed at certain states of the tide; the velocity of the river was at that time increased, and therefore scour took place. Another point of great importance was that in tidal estuaries there was a very much larger volume of water flowing in and out, therefore preventing or diminishing the formation of a bar which was generally liable to form along the coast, owing to the heaping-up action of the sea. The River Mersey, to which reference had been made, was but a very small river in regard to its freshwater flow, which amounted only to about 2,000,000 cubic yards in every tide, whereas its average tidal flow amounted to about 500,000,000 cubic yards, or about two hundred and fifty times the freshwater flow. That showed how important an element the tidal flow formed in rivers of that class. He thought it could hardly be said that it was the tidal flow that acted as the recuperative agent in the estuary of the Mersey. It was rather the shifting of the low-water channel, which maintained the equilibrium of the estuary; for the modifications in the direction of the ebbing current through the unstable sands caused the channel to vary from one side of the estuary to the other. If a fixed channel were formed, up which the flood could come and the ebb tide go down, that large scouring reservoir would be lost, and the bar, or the channel over the bar, would consequently be injured. It was different in the case of non-tidal rivers. They had merely the freshwater flow which descended continuously towards the sea, and as they came into the sea the fall was absolutely obliterated, and they therefore deposited by

Mr. Vernon-Harcourt. degrees the sediment which they carried down in their course. Then, at certain times of the year, the variation of the out-flow of tideless rivers was very great; whilst in tidal rivers, there was only the variation between neap and spring tides, which was much less than the variation between the flood stage of a river and the summer flow. In non-tidal rivers there was, as far as he knew, only one method of improvement, namely, by selecting one of the mouths of the delta and concentrating the current in it, so as to gain depth by contraction of width, and, as it were, carrying the banks of the river beyond the bar by projecting embankments or jetties. That method of improvement had been successful on the Mississippi and on the Danube. It had been attempted on the Rhone, but without success. One reason perhaps for the want of success was that the other branches of the Rhone were closed up, and that therefore, although there was an increased scour, there was also an increased sediment, because although it might seem at first sight advisable to get all the scour that could be obtained in a non-tidal river, in order to sweep away the bar, yet it should be remembered that the more the water the more the sediment brought down with it. Another point in connection with non-tidal rivers was the question whether there was a littoral current across the end of the channel to be improved. If there was, then the sediment which would be carried out to sea by the prolongation of the channel by jetties might be swept away; but if there was not, if there was a large amount of sediment in the stream, and if the slope of the sea in front was flat, then probably the improvement of the river was practically unadvisable. The Rhone brought down a large quantity of deposit, which, having been concentrated into one mouth, caused an increased rapidity of advance of the delta in front on a foreshore which had only a moderate dip seawards, and where the supposed littoral current was only at the surface. Consequently the improvement in depth, which at first resulted from the concentration of a larger flow over the bar, was not maintained; and the outfall was now in a worse condition than before the commencement of the embankments. The Author appeared to think that there had been very few cases of the improvement of non-tidal rivers except for the purpose of the prevention of floods. He had mentioned the Rhone, but there were also in America, on a smaller scale, rivers flowing into large inland lakes, with ports at their outfalls, as in the case of Chicago, Buffalo, and Oswego. The rivers bearing those names had been trained by means of cribwork jetties into their respective lakes; but that

Mr. Vernon-Harcourt.

method, though it had succeeded to a certain extent, and had been also aided by means of dredging, had been found not to give a sufficient outlet to the trade of these ports, though adequate in other instances. As in the case of the Mediterranean shores, the Americans, in the three ports he had mentioned, had been recently making harbours by the side of the rivers in the lakes themselves by means of cribwork breakwaters; thus avoiding the river mouths, but not so much because they could not improve the mouths as because they thought it advisable to have more accommodation for trade than the narrow outlets of those rivers would afford. In regard to the Tiber, the Author had submitted two distinct problems. One was the improvement of the outfall, and that he should have thought from the title of the Paper was its main object; but the Author had also brought forward another point common not only to rivers flowing into tideless seas, but to all rivers, namely the prevention of floods. Unfortunately he had not said much about the improvement works that had been carried out at the Tiber outfall. He had stated that there had been some improvement in depth recently effected at the entrance, but he had not given any details about the improvement works that had been carried out at one of the mouths of the Tiber. He had not stated what sediment was brought down by the river, nor what was the slope of the sea in front, which were important elements in the question as to whether the Tiber was capable of improvement or not. He thought it possible that what had been done in the small lake rivers of North America might also be carried out on the Tiber, that the improvement of the river might be helped by dredging. He knew that dredging had proved useless in the case of the Mississippi except within the jetties, but he thought that jetties with dredging might improve the bar in front of the Tiber. He did not agree with the Author that the absence of any suggestions for improving the main outfall of the Tiber indicated that the improvement of its entrance was impracticable, for neither on the Mississippi nor on the Danube had the main outfall been selected for the improvement works. There was also another point that he thought worthy of notice, namely whether it would be possible without considerable works, even if the outfall of the river was improved, to convert the Tiber into a good navigable river? He could only go by the information given in the section, Plate 1, Fig. 2, but he thought it was doubtful whether without very large works it would be possible to improve the river adequately above its delta up to Rome. With regard to the flood flow, it appeared to be backed up at the head of the delta, and the Author

Mr. Vernon-Harcourt. had not mentioned whether there was any impediment at the head of the delta. There was an impediment, and it had to be removed, at the head of the Mississippi South Pass; and it was possible therefore that a bar might be formed not merely at the outfall but at the head of the navigable channel of the Tiber outfall. The Author had also mentioned with regard to the Tiber that as a non-tidal river it was peculiarly meandering. Sir Charles Hartley had mentioned the case of the Seine, the meanderings of which were certainly much greater than those of the Tiber. Including the whole tidal Seine from Havre to the lowest weir on the Seine, the distance in a straight line was 45 miles, but by the river channel it was 95 miles, or an increase of 111 per cent. as compared with 45 per cent. in the Tiber, so that a circuitous course was not a peculiarity confined to non-tidal rivers. With reference to the question of floods, the Author evidently preferred the method of embanking, and no doubt for preserving Rome from floods that might be a most suitable method. But one great objection to embanking rivers for the prevention of floods was that when a river was embanked its bed became, as it were, a place for deposit. People neglected to clear out the bed of the river, trusting to the embankments, and the river continued to silt up; the embankments had to be raised, and unless they were raised to a height above any possible flood, the injury occasioned by very high floods might be as great as that from floods without any embankments. As to reservoirs, he thought that in most cases they did not offer a practicable mode of preventing floods. It might possibly be desirable, at present, to maintain the marshes above Rome as reservoirs for flooding on account of Rome itself; but it would seem the better course to deepen the river below Rome, to improve it also above, to remove the old bridges with their obstructive piers, and rebuild them with adequate waterways, and to straighten the river, as had been done in the case of the Mississippi, and in that way improve the river against floods, not by embanking but by dealing with the channel itself. Such works would also tend to increase the navigable capabilities of the river.

Mr. Redman. Mr. J. B. Redman remarked that in the previous session a Paper had been read descriptive of a tidal river debouching into a tidal estuary;[1] the present Paper was on a river discharging into a tideless sea. On the previous occasion some startling deductions were brought forward; but there were none in the present Paper. The conclusions drawn in the summary of the two classes of rivers

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[1] Minutes of Proceedings Inst. C.E. vol. lxxviii. p. 212.

Mr. Redman. were, he thought, in the main consonant with physics and with experience in such matters. The Paper had a dual interest. First, it directed attention to the fact that the naval supremacy of England, on which it had hitherto prided itself, was in a great measure due to the great range of tide upon its seaboard and in its estuaries. It was secondly of great interest, as showing the physical changes in the metropolitan river of Italy, the "Yellow Tiber," and the efforts that had been made by men who desired the welfare of their country, from the great Roman emperors down to the time of the modern Italian patriot, to improve the river; but with comparatively small results. The Paper had been necessarily historical and retrospective, and references had been given to a large number of memoirs and treatises bearing on the same subject: but the Author had omitted mention of a Paper (antiquated no doubt in some respects, inasmuch as it dealt with the subject as it presented itself forty years ago), by the late Sir John Rennie, Past-President Inst. C.E., "On the Ancient Harbour of Ostia."[1] That Paper dealt with the historical aspect of the question with great perspicuity, and the outcome of it was, that over a period of from two to three thousand years, the progression of the delta was more than 3 miles. It was also curious as showing the progressive change in the Institution, seeing that a Paper devoted to that special subject written by an acknowledged authority of the day, provoked a discussion which induced only two members, in addition to the Author, to join therein, one the late Mr. F. Giles, the other Mr. W. Thorold. Sir John Rennie did not bring forward any special views of his own; but he did theorize to the extent of saying that he thought that when within the capes on either side of the outfall the recession in the line of shore was filled up by the sedimentary deposit, the action would cease, and the outfall would become free. Plate 1, Fig. 7, showed the converse state of things—the delta progressing 4 miles into the sea very much like the shingle promontory at Dungeness, with a very deep bay at each side. In regard to the question of the improvement of the Tiber, the Author had divided the river into sections. As to the outfall, he was inclined to agree with Sir Charles Hartley, that the Author had taken a somewhat pessimist view. The shore was steep, and deep water was rapidly reached. The Author had stated that the principle of leading up the low water of a river into the heart of a country, and thereby developing the scour and

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[1] Minutes of Proceedings Inst. C.E. vol. iv. p. 307.

Mr. Redman. increasing the navigation, as adopted in this country, was not applicable to the Tiber. Manifestly it was not, inasmuch as there was no low-water and no high-water, but a constant level. But were the outfall deepened by cribwork or auxiliary parallel works on either side, assisted by dredging, and were the great masses of flood-water delivered into a body of its own element, surely the outfall would be proportionately increased in capacity instead of impinging upon a shallow and being deflected right and left and upwards by sedimentary deposit. As to the upper river, it would be remembered that in the inquiry of the Commission of which the Duke of Richmond was chairman, the question was brought forward in regard to the upper valley of the Thames, and the proposition was mooted of applying lateral embankments to the right and left banks of the upper river similar to those adopted for the tidal portion. He had no hesitation in saying that if that mode of procedure had been carried out, it would have been most ruinous. There might not be the same æsthetic objection to such a course in the case of the Tiber; but there was the same practical objection, and manifestly the best mode of improving the drainage capacity of the upper river was by deepening, rather than by raising the parallel embankments.

Mr. Giles. Mr. A. Giles, M.P., said that if one thing had struck him more than another on reading the Paper, it was that Rome, being a city of so much importance that it was once called the Mistress of the World, and which had been in existence over 2,500 years, should have submitted to the constant damage from the enormous floods passing through the city. It did not say much for Roman engineering, although there was abundant evidence of engineering power in the drainage of the city, in the Cloaca Maxima, and in the Aqueducts. There could be no doubt that the plans proposed by the Italian engineers had been decided upon with reference to their cost rather than with reference to their general adaptation to the objects in view. The plan by Canevari, and altered to some extent by Vescovali, appeared to be a step in the right direction; but it would be impossible to judge what the effect of the alteration would be without some comparative cross-sections. It would be seen that the flood-line went over the top of the parapets of the old bridges; and the sections of the flood showed that great dams were caused by those obstructions. The Italian engineer, Possenti, proposed to straighten the river below Rome. It was stated in the Paper that the sinuosities of the river amounted to 45 per cent. more in length than the straight line, and the Italian engineers differed so much as to the results of the proposed straightening, that one of them stated that the flood line would be lowered only 1·8 foot, while another stated that it would be altered 4·92 feet. The question seemed a very easy one to settle, and he could not understand how it was that the Italian engineers could differ so widely. Possenti's plan was to cost £127,000, and, seeing that the government was going to spend between two and three millions in the alterations being made, he thought that the £127,000 would have been money well spent, in addition to that required for widening the channels through the City of Rome. In former times the port was at Ostia, which appeared to have had a life of about 700 years. The encroachment of the delta rather blocked it up, and the expedient was adopted of cutting a canal in another direction to the sea, the life of which being only 100 years, showed, he thought, some bad engineering. He could not help thinking, that if the delta had been taken in hand at Ostia, a new cut would have been unnecessary. It appeared from the section that the height of the flood-line at Ostia above the sea-level was only 11 feet. That would not have prevented a port being made at Ostia, and if proper means had been taken above, the 11 feet might have been reduced to 7 or 8 feet. There were many instances of ports on rivers subject to floods of that height, and he thought it would have been better to have maintained the port of Ostia where it was, than to have attempted a new port. At the same time with a river rising in flood some 64 feet, and with a volume of water rolling down fifty times the amount of its summer flow, there was no doubt a very great difficulty. As a rule, rivers subject to those variations were not so well adapted for navigation as for flood-discharge; this might be further proved by the port of Rome being now fixed at Civita Vecchia, considerably to the north, where there was no river. The Author had stated that tidal rivers had no true deltas, but Mr. Giles did not know what was the difference between a delta and a true delta. There were many examples of tidal rivers which had what he should call deltas—the Mersey, the Dee, the Ribble, and the Tees, for example. A delta, he imagined, meant an accumulation of sand at the mouth of the river; if not, he did not know how a delta could be described. With regard to the sinuosities of the Mersey (Plate 1, Fig. 1), he might mention that the point to the right where the two lines came into one, was simply decided by a ledge of rocks jutting out from the northern shore, and although one line showed an extreme curvature to the south, and another almost to the north, out of twenty plans of directions, made during the last Mr. Giles.

Mr. Giles. sixty years, four or five took the course right through the centre of the estuary. As to tidal rivers with bars, it was well known that bars were objectionable. The sections (Fig. 1) showed the difference between the bar of the Tiber, and the bar of the Mersey; but he did not think any one could form an adequate conception of what the bars really were without seeing a longitudinal as well as a cross-section. In the case of a large river like the Mersey, with its enormous commerce, it was remarkable that no attempt had been made to improve the bar. Remembering that sixteen millions had been spent on the Liverpool Dock Establishment, he thought that a million or two more spent in that direction would not be money thrown away. The depth of water on the bar now varied from 9 to 10 feet, but it might probably be increased to 20 feet by proper works. Vessels drawing from 25 or 26 feet sailed from Liverpool; and if a vessel arrived at dead low water, she would find only 10 feet of water on the bar, and would have to wait for three hours' flood before she could get up. At certain times a vessel might have to wait six or eight hours before being able to get in, and that was a circumstance which he certainly thought cast some reflection upon the management of the Mersey. The question of rivers running into tidal seas had been often considered, but the subject of rivers running into tideless seas was a comparatively new one to English engineers, and deserved serious attention.

Mr. Wilson. Mr. WILLIAM WILSON said the Paper related to a subject on which he had always been to a large extent engaged, having had to examine and report upon a great many non-tidal rivers both in Europe and in America. But the chief point of interest to him was the reference to the River Tiber, with which he was intimately acquainted. He was in Rome at the time of the flood in December 1870, and saw what happened when the water rose at the Ripetta to 17·20, being 3·70 above the street, and overflowing all the low-lying districts. He went again to Rome immediately after the flood, and made a careful examination of the river; and he came to the conclusion that the obstructions which caused the floods were encroachments, imperfect water-areas under many bridges, and ancient ruins which had never been removed from the river. He particularly examined the Ponte Trionfale which had been removed, but some piers up to the lowest water-level were standing, and there was an enormous accumulation of deposit behind them. Ponte San Angelo had much too small a waterway. During the flood he observed that the water below was within an inch or two of 2 feet below what it was above, Mr. Wilson. showing that the bridge caused an immense interruption to the flow. Another impediment was the Ponte Rotto, and a bridge with large spans, which had been built upon the same site as two old ones. Two ancient bridges had been removed, one after another, but all the piers existed and caused great obstruction. Another serious matter was that, when the construction of the new buildings began, the builders were allowed to bring their refuse and deposit it over the quays into the Tiber at various points all the way down. He visited Rome on various occasions afterwards, and every time made accurate examinations. In 1875 he went there at the request of the Duke of Sutherland and Mr. John Fowler, Past-President Inst. C.E., to investigate and report upon all the schemes then proposed. Commissioners had been appointed, and at least half-a-dozen schemes had been suggested for getting rid of the obstructions. The principal projects were those of Garibaldi, Gioia, Baccarini, Vescovali, and Canevari. Garibaldi's scheme was to divert the Tiber from near the mouth of the river Aniene, and take it entirely away from Rome for the main discharge. After examining the various projects, he came to the conclusion that Garibaldi's diversion was most undesirable, and there was a strong feeling among the population to the same effect. Garibaldi showed him every attention, and discussed the matter with him. Mr. Wilson persuaded him to re-consider his project, and ultimately to abandon it. He then made his report, which coincided almost entirely with the plan shown by the Author, except that he altered Ponte San Angelo. There was a great desire to keep it as an ancient structure, and he altered it to get more waterway, but he did not put in the works above because he assumed that the alteration of the Tiber below would prevent overflow at the Ripetta. The river now varied in width from 30 to 80 metres, and he proposed that the whole should be made with walls all the way down to a width of 100 metres, all excavated and dredged down to a level of 2 metres below lowest water. The works would cost, according to his estimate, 25,000,000 lire, exclusive of the expropriation of property, which at that time had not been ascertained. He was sure that if the works now going on were carried out, there would be no more such floods in Rome; for the obstructions in the river had more to do with them than the deposit at the delta.

Mr. Hutton. Mr. Darnton Hutton asked for some further description of the bar at the mouth of the River Tiber, of what it was formed, where it was situated, and whether it changed much in height or position? In connection with this subject he should like to say something as

Mr. Hutton. to the difference in the behaviour of detritus of different specific gravities, partly because he had never met with any clear explanation of the point, and partly in the hope of eliciting discussion on it. The two principal forms of detritus which had to be dealt with in rivers and harbours were sand and mud. The specific gravity of sand was about 1·5, and he believed that, excepting when stirred up by storm-waves, it was rarely, if ever, held in actual suspension, but was rather rolled along the bottom by the current. Now if the bottom were as smooth as a billiard-table, and if the particles of sand were perfectly spherical and perfectly concentric with respect to their centres of gravity, they might perhaps move straight forwards; but as the bottom was not smooth, and the particles of sand were irregular, the current pushed them sideways as well as forwards, and the result was a deposit on each side of the line of current. As that side-deposit increased in height the slopes became too steep for the particles of sand to climb, and they were then carried forward to the end of the bank, where they could again escape sideways, thus forming the tailing out of the banks which was to be found in sand-bearing rivers and on sandy coasts, such as the Thames, and the Clyde, and the coasts of Norfolk and Suffolk. He might observe with respect to the motion of the sand along the bottom that he had frequently, when diving in the helmet dress, found it in motion, the top for 6 or 8 inches being very much as Sir John Coode, Vice-President Inst. C.E., had described the surface of the Shambles off the Bill of Portland, but he had never in moderate weather found the sand in suspension. As a general rule sand seldom travelled far; usually it formed lateral banks on each side of the current, and it might be taken as a general principle in designing harbours in sandy localities of no great exposure, that it was well to avoid currents as much as possible. Of course he did not by any means state that as a principle of universal application, because there were probably no two harbours with precisely the same characteristics, and he wished to guard himself against the supposed suggestion of any universal principle, however apparently innocent. At the harbour of Ymuiden, for example, where the principal deposit was sand, the formation of the banks at the side of the currents was clearly shown. The flood tide there ran to the northward, parallel to the shore, at a velocity during springs of about 2 miles per hour, and the ebb to the southward, but at a much less velocity; and when the piers were built the current was diverted, causing a deposit to form almost at once in the outside angles of the piers; but having thus formed, to suit the new direction of the current, the bank had for the last eight years shown no sign of further increase, and might be regarded as permanent. In the same way a deposit tended to form inside the piers alongside the entering current, but there was no sand deposit further up the harbour where there was no current, or rather perhaps he should say, because there was no current there, and the water was less disturbed by the passage of vessels. On the other hand, the failure of the attempt to scour out the channel at the Hoek of Holland, by works very similar to those which had proved so successful at the Mississippi and at the Sulina mouth of the Danube, showed the difficulty of getting rid of such a heavy deposit as sand by means of a current. Mud, however, the specific gravity of which very slightly exceeded that of water, was easily held and easily kept in actual suspension; it was swept along with the current, had less tendency to form side-banks, and deposited slowly over large areas when the force of the current was spent and the water comparatively still. When, therefore, the principal deposit was mud, it was frequently desirable to encourage a current of equable and sufficient velocity in order to prevent deposition. Thus the proposed new harbour at Ostend was so designed as not to interfere with the current of the Scheldt, and it was on that principle that the Mississippi and Sulina works, before referred to, had been carried out. Many sea harbours also, such as Portland, Plymouth, and Cherbourg, owed their freedom from deposit in great measure to their non-interference with existing currents, and it was the neglect of this principle at Flushing harbour which caused the formidable deposit with which it was encumbered. Mr. Hutton.

In speaking of the formation of sandbanks alongside the currents, he had referred only to cases of moderately sheltered situations, and where the sand was uninfluenced by the action of storm-waves and ground swells, both of which would undoubtedly stir up sand from considerable depths, and hold it in actual suspension; and in many cases of great exposure, such for example as Port Elizabeth, more sand was, he believed, moved in one storm than in many recurring tides.

Mr. Latham. Mr. **Baldwin Latham** observed that about thirty years ago Mr. W. Hopkins, of Cambridge, calculated that the scouring power of a river was in proportion to the seventh power of the velocity (not the sixth), which was probably as correct in a natural stream as the other was in an artificial channel. He thought that there must be some great error in the gaugings made by the Italian engineers. The Author had not given the figures on his own authority, but on the authority of those who had

Mr. Latham. calculated them. It was well known, however, that the quantity of water which would be yielded by a large area of drainage, especially in flood-time, was much less in proportion than that from a small area. In the case of the Tiber catchment-basin the altitude was considerable and the area very large. The average rainfall of the district being given, the means existed of comparing it with the mean discharge given in the Paper and of arriving at the percentage run off from that large area; and when the figures were compared with those of other drainage areas, it was quite clear, having regard to climatological influences which were at work, that there was a considerable error in them. With reference to the Thames, the experience of last year had shown that it had a much smaller minimum flow than had previously been imagined. Allowing for the water extracted by the water companies and passing over Teddington Lock, it could not be taken at more than 9 cubic feet per minute per square mile for the 3,676 square miles above Teddington. The area of the Tiber catchment basin was 6,455 square miles. The average annual rainfall within the Thames basin for fifteen years, 1866–1880, had been calculated at about 28 inches, and it had been shown by Beardmore's careful calculations and experiments that of that quantity not more than 7·8 inches flowed off, and that was probably somewhat in excess of the true quantity. The mean flow of the Thames was taken at 30 cubic feet per square mile, but in the case of the Tiber, the minimum flow was 33⅓ cubic feet per square mile. Of course the flood-flow could not be ascertained, because there were such various estimates, showing that the gaugings could not have been carried on in a very scientific way. The maximum flow in the Tiber of 5,000 tons per second gave a little more than an inch per day flowing off that very large area, whereas the largest flood known in the Thames through a much smaller area only gave a little less than a quarter of an inch. Again, the maximum flood-flow of the Thames was 360 cubic feet per minute for each square mile, which was 40 times the minimum flow. In the case of the Tiber, the maximum flood was taken at 5,000 tons, which was 1,668·4 cubic feet per minute per square mile, or 4·6 times as much from the larger area of the Tiber as from the smaller area of the Thames. Nothing had been said as to the geological formation of the area, but it might be taken as a principle that when the geological formation was porous, and extremely absorbent of rain, the rain would be given out as perennial water at the low periods, and that those rivers whose watershed had the largest amount of that porous soil would have

Mr. Latham.

the largest mean flow, and correspondingly a much smaller flood-flow; and impervious geological strata would yield large floods but very little perennial water, and have small minimum flows. But in the case in question, there was an enormous quantity of water flowing at the minimum period, and a correspondingly large quantity in time of flood. That might be so if the grounds were so high that they were covered by perpetual snow, which was melting in summer, but the elevation was not sufficiently great, and it appeared that the great floods had occurred at a time when they were not so much assisted by the melting snow. At the period when the minimum flow took place, all snow would have disappeared from the Tiber drainage area. The facts were simply these. In the Tiber, according to the gaugings, 61·6 per cent. of all the rain flowed off; in the Thames the amount was only 27·9 per cent., and in the Lee 25·5 per cent. The River Seine also gave about the same percentage as the Thames. He therefore thought the figures were over-stated. There appeared to be a notion on the continent that there had been a great diminution of water-supply, and a corresponding increase in the amount of floods in recent years. About ten years ago the Imperial Academy of Science of Vienna issued circulars to scientific bodies to get information on the subject, and he had been recently drawing up a report for a Committee that had been considering the question for some time.[1] Where rivers were constantly extending in length from the increase of their deltas, it was only natural to find that modern floods rose to a much greater altitude than ancient floods; for when a length of 3 miles was added to a river, it would require a much greater fall to discharge even the same volume of flood-water as that which flowed down in former years, and that could only be obtained by increasing the height of the flood inland. He had been collecting statistics in Great Britain, which proved that there was neither a diminution in the water-supply nor any increase in the height of the floods. The highest flood known in the Thames in the present century was in 1809, and the next in 1821, since which time there had been no floods so great as those. Probably river-improvement might have had something to do with this state of things. Since 1821 the highest flood was that in February, 1883. The deltas of rivers discharging into tideless seas, as in the case of the Nile, were due not only to the volume of solid matter brought down, but still more largely to the destruction of microscopic life at the point where the fresh water met the

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[1] Quarterly Journal of the Royal Meteorological Society, July, 1885.

Mr. Latham. sea-water. Two-thirds of the delta of the Nile had been shown to be due to the latter cause, and not to the sedimentary deposit moved down the river. So long as those deltas existed and grew, a rise in the flood-water might be anticipated, unless corresponding engineering works were carried out to moderate the work which nature was performing.

Professor Shaw. Professor HELE SHAW asked the Author whether he really meant that tidal rivers had no true deltas? As to the river Ganges, in spite of what Mr. Vernon-Harcourt had said, when it was remembered that its navigation up to a certain distance was carried on to a great extent by means of tides, it would be admitted that it was a tidal river. It had a delta much larger than any of those rivers mentioned by the Author. The Indus also had a large delta, more like that of the Tiber in form. It was 130 miles across, and 70 miles to the head, the tide rising the whole distance. Many other cases might be mentioned, and some explanation of the Author's statement was needed, even with the qualifications which he had given. The Author appeared to give the credit of recuperative power entirely to the flood-tide; but there were cases (certainly many on a small scale) where the cut-offs were made by means of the flood from above. In the Mississippi, he believed, extensive cut-offs were made; the pilots being always on the look out for them. He knew that this kind of action occurred in several small streams. He could not agree with the Author that non-tidal rivers had no such recuperative power. Their sinuosities, it was said, tended to increase in perpetuity; he should like to know a case where that was so. It was generally considered that the sinuosity tended to increase, until the surface slope was so reduced that the velocity fell to a point such that no further erosion took place, at any rate for a time; and the bed did not change until there was some flood, or some out of the way occurrence causing alteration in the channel. As to the statement that the first river-conservancy dated from B.C. 53, that might be technically true as far as the actual appointment of a board of conservators, but it was not the first case of river-conservancy; four thousand four hundred years ago the Chinese rivers were conserved on the most extensive scale. The Hoang-ho, for instance, baffling the skill of many engineers, was dealt with by the whole resources of the Empire, and for a thousand years was carefully conserved. The same had been the case with many other large rivers—the Euphrates for example. The Author appeared to have based his conclusions almost entirely upon the case of the Tiber. Mr. Hele Shaw would contrast it with a river of which he

Professor Shaw.

happened to know a little—the Avon at Bristol. The alterations which were made in the latter many years ago comprised the formation of a basin, and the making of a new straight cut, and a floating harbour of 3,500,000 square feet of surface. There was also another cut, and a dam was placed across the old bed of the river at Netham, so that the tide, which formerly flowed up the Avon and the Frome, could not, except at springs, flow further than the dam; consequently a large amount of tidal water had been cut off. He had not found any testimony as to the diminution of the channel below. Although a considerable quantity of the tidal water had been cut off, the scouring power appeared to be sufficient to maintain the channel. A case, though not on the same scale, of a river flowing into a tideless sea occurred in the same neighbourhood. The Gloucestershire Frome, which flowed into the floating harbour so made, it was true, did not, in the highest flood, bring down more than 60 tons in a second; but the point to which he desired emphatically to call attention was that it did bring down a large quantity of water. Some was carried off by a culvert 3 feet 6 inches in diameter, but that was not sufficient to carry off all; a large volume of water passed into the floating harbour, but since it had not much matter in suspension, it did not cause a large deposit, and this was easily kept down by a rudimentary dredging apparatus. On the other hand, where the tidal river, which had a large amount of matter in suspension, came up to the dam, and there became slack water, an enormous deposit took place, sometimes 3 inches in a tide, 6 or 7 feet deep in places on the river in the summer months, and in some places 15 feet had been known to collect, which had to be scoured away by the fresh water coming down in the spring. If it were not for the fresh water coming from above, which left very little deposit, the bed of the river would soon be silted up.

Mr. Shelford.

Mr. SHELFORD, in reply to the discussion, said he took credit to himself for having given some prominence to the formula of Mr. Airy, which had been so fully corroborated by the independent calculations of Mr. Law. It must, however, be used with judgment. He had applied it in the Paper to the deposit of detritus as a consequence of diminution in velocity, and he considered this strictly correct; but it did not apply to the transport of silt mentioned by Mr. Gordon, as it referred not to the quantity of silt scoured, but to the size of loose particles, having the same specific gravity, moved or, according to Mr. Law, turned over or rolled by the stream. The following Table showed how this was confirmed by Mr. Blackwell's experiments:—

Mr. Shelford.

ANALYSIS of MR. BLACKWELL'S EXPERIMENTS on the TRANSPORTING POWER of WATER at VARYING VELOCITIES (1857).

Description of Substance.	Cubic Contents.		Velocities.		Increase of Contents of Substances moved.	Increase of Velocities.	Sixth Root of Increase of Contents.
	Cubic inches. 1.	Cubic inches. 2.	Feet per second. 1.	Feet per second. 2.			
Brickbats .	2·59	18·5	1·75 to 2·00	2·75 to 3·00	7·14	1·37 to 1·70	1·38
Brickbats .	4·76	18·5	2·25 to 2·50	2·75 to 3·00	3·97	1·10 to 1·33	1·26
Oolites . .	2·39	17·68	2·00 to 2·25	2·75 to 3·00	7·40	1·22 to 1·50	1·39
Flints . .	1·95	10·37	2·50 to 2·75	3·00 to 3·25	5·32	1·09 to 1·30	1·32
Slate . .	2·38	9·06	2·00 to 2·25	2·75 to 3·00	3·81	1·22 to 1·50	1·25

The velocities compared were those at which the substances severally commenced to move.

Several speakers appeared to question his statement that tidal rivers had no true deltas, and the Ganges, the Indus, the Irawadi, and other rivers in the Bay of Bengal had been mentioned by Mr. Thelwall, Professor Hele Shaw, and Mr. Gordon; the Mersey, the Dee, the Ribble, and the Tees by Mr. Giles, and the Seine by Mr. Shoolbred, as examples of tidal rivers with deltas. But Mr. Shelford would rather point to them as instances of rivers such as he had in mind, and would add those which flowed into the Lincolnshire Wash and the Rhine, and reassert that they did not possess true deltas in the sense of a "talus" consisting of detritus brought down by the river and continually extending; but that the outfalls of such rivers were for the most part encumbered by sands, the origin of which was a frequent subject of dispute, and whose deposition, depending upon the forces at work outside, either entirely or to a much greater extent than was usual in tideless seas, was uncertain and abnormal, and distinguished them from true deltas.

The datum of his section of the Tiber had been referred to by Sir Charles Hartley. The zero of the Ripetta gauge had been adopted by the Italian Government Commissioners as the baseline, and they had determined that the mean level of the sea was 0·971 metre below it. This zero, being a fixed and well-known point, was a more satisfactory datum than the sea-level, which **Mr. Shelford.** was subject to numerous fluctuations, depending on the force and direction of the wind. The amount of suspended matter in the water was as follows:—

RIVER TIBER.—*Extract from the Report of the Minister of Agriculture, Industry, and Commerce.*

PHYSICO-CHEMICAL OBSERVATIONS on the WATER of the RIVER TIBER, 1872–1877.

Year.	Suspended Matter. Grams per Cubic Metre.			Suspended Matter. Grains per Gallon.		
	Mean.	Max.	Min.	Mean.	Max.	Min.
March 1872 to Dec. 1872 .	826·9	28,600	10	57·883	2,002·00	0·7
1874 . . .	1,254·57	21,804	74	87·819	1,526·28	5·18
1875 . . .	1,284·4	42,646	30	89·908	2,985·22	2·1
1875 . . .	1,498	31,008	44	10·486	2,170·56	3·08
1876 . . .	1,112·49	24,634	6	77·874	1,724·38	0·42
1877 . . .	1,158·16	34,027	12	81·071	2,381·89	0·84

and the calculated velocity of the current through the urban Tiber in flood was 10 to 12 feet per second, and in dry weather it was from 1 foot to 1½ foot per second.

In answer to Mr. Thelwall, the Italians had provided for a discharge of 5,000 cubic metres (say tons) per second in the new works in the Tiber.

He thanked Mr. Vernon-Harcourt for the general confirmation of his views on most of the points. The slope of the sea-bottom in front of the outfall was obtainable from the chart (Plate 1, Fig. 3), and might be taken at 1 in 100. The increased length of the Seine due to its meanderings was only a correction to be admitted if the material of the valley of the Seine was alluvial, which he doubted; and he was still unaware of any tidal estuary where the tide was free to act on the soil (as the water of the Tiber was) in which the sinuosities increased the length by 45 per cent.

Several speakers, including Mr. Redman, did not quite seem to appreciate the difficulty of improving the main outfall of the Tiber. No doubt it could be deepened by parallel works and dredging, but when deepened there would be no sufficient volume of water to maintain it, so that the dredging would have to be continuous, particularly as the formation of the bar across the mouth would continue. It would require very flourishing navigation, instead

Mr. Shelford. of two or three floods in a century, to make this expense worth incurring.

Grave doubts had been expressed by Mr. Baldwin Latham about the accuracy of the gaugings of the Tiber, but he had mistaken the amount named in the Paper, and had adopted 5,000 tons per second as the maximum, whereas he should have taken 2,500 to 3,000 tons as the maximum flood-discharge in 1870. This would give about ½ inch per day flowing off the drainage area. The rainfall which produced this was gauged at Perugia, Rome, and Civita Vecchia, and the depth immediately before the inundation varied from 1·41 inch to 2·44 inches in twenty-four hours, and averaged 1·89 inch, so that about 26·5 per cent. was discharged. No doubt three rain gauges over so large an area were insufficient, and the result was only approximate, but there could be no comparison for this purpose between the Tiber and the Thames, as their gathering grounds differed in elevation and strata. He did not attribute the recuperative power of a tidal river to the flood-tide only, but to the combined action of the flood and ebb, though his general observation was that a change of channel in an estuary choked with sands commenced on the seaward side, and this was due to the action of the flood tide.

The case of the Avon at Bristol, which had been referred to by Professor Hele Shaw, had done duty before at the Institution, and belonged to a class with whose characteristics he was familiar, but he could not see its applicability in the present instance.

Correspondence.

Mr. Atkinson. Mr. W. Atkinson observed that the Author contended that in tidal rivers a power was exercised by the flood-tide, which broke through sand-banks, thereby giving a straighter course to the ebb-tide, and that the sinuosities in non-tidal rivers tended to increase in perpetuity. It would be difficult to find an example which so completely contradicted the above as that of the 14 miles of the Parret, taken from its confluence with the Bristol Channel. The direct distance was only 7 miles. The flood-tide, at a part where there was a large sand-bank, did not cut through it, though the flood ran up quickly with a marked head. But what was peculiar and conclusive in this very sinuous river was that, in spite of the tide, its course had been gradually determined by the deposit of the sand, &c., on the flats brought up mostly by the tides. The land-water determined, in this case, the sinuous character of the river

Mr. Atkinson.

in spite of the flood-tide. The Author asserted: "In tidal rivers the maximum flood-channel necessary for the discharge of fresh-water floods is maintained by the regular action of the tides. The tidal reservoir is always in excess." Surely he did not mean that in time of flood-tide and a flood from the land the tidal reservoir was in excess; the reverse was often the case. The Author's dictum conveyed the idea that tidal rivers were kept open by the action of the tides, and that the land-water was never a necessary element. It was understood that he referred to the tidal portion only. It would be admitted that river-courses had been originally formed by land-water, and that therefore that water had a marked power. Also it might be taken as granted that land-water brought down detritus. Now, manifestly there must be a greater tendency to deposit detritus in a tidal river than in a non-tidal one, as far as the increased elevation due to the tide was concerned during the flood-tide, and it was a question how far this was counterbalanced by the lower level of the ebbs.

Judging from many well-known cases, the character of this deposit at the mouth of a river did not appear to depend upon whether the river was tidal or non-tidal, but upon its volume; the quantity and quality of the detritus; the ocean-currents, or run of the tide, and the contour of the adjacent ground. Indeed, as at Santander, where the rivers ran first into so large a bay that the detritus might be assumed to deposit in it, there was nevertheless a bar which, from the contour of the coast, might be fairly assumed to have its origin in the ocean. It was well to note that this bar existed in spite of the enormous tidal basin of the bay, and the consequent ebb-scour from so large an area through so narrow an entrance.

Returning to the question of the tide being the power which kept a river open, it was of the greatest moment to consider whether the tide brought up detritus. Very contrary views had, even lately, been expressed, but the divergence depended mostly on the various conditions under review. Taking such rivers as the Avon and the Parret, into which the tide carried up an enormous amount of detritus, it could not be affirmed that the tidal action kept the channel open, for it was only necessary to stop the land-water, and immediately the upper end of the tidal basin would silt up, and in a few years the whole channel would be obliterated. The land-water removed the deposit brought up by the tide at the upper end of the basin, and thus it was preserved, and the force of the ebb was undiminished, and kept clear the lower end of the river; but where the tidal water did not

Mr. Atkinson. bring in appreciable detritus, it could not be denied that its action must be beneficial, the extent depending upon the form of the channel.

The Author had referred to Mr. Airy's formula, "that the capability of a stream for moving detritus varies as the sixth power of its velocity," and then said, "it follows that the scouring-power of a stream varies as the cube of the fall." Now the term "scouring-power" undoubtedly conveyed the idea of work being done, but the effect could not be greater than the cause, and the cause was the potential energy of the water, due directly to its height, and therefore fall, and not to the cube of the fall. However, if the relative velocities were taken, the work that any mass of water could do at different velocities was in proportion to the square of the velocities, that being the relation of their kinetic energies. Or if it was desired to express the work done by a thread of water at different velocities in the same time, the relation would be as the cube of the velocities, for the quantity of water would be increased as the velocity. From the above it was clear that the term "scouring-power" should not be introduced in connection with Mr. Airy's formula, which did not refer to work, but to a statical condition in which the tendency of a particle to resist moment was balanced by a pressure due to the velocity of the water.

Mr. Cay. Mr. W. D. CAY remarked that the phenomena of non-tidal rivers, and their contrast to those of tidal rivers, were mainly due to the difference in the specific gravities of salt water and fresh water. The fresh water, when in conjunction with sea-water, was borne up and floated by it, and so prevented from scouring the bottom. As respected navigation, therefore, an estuary was better without its river, which should be diverted out of it where possible. He had proposed this course in 1877 for the improvement of Aberdeen harbour, where the river deposited much silt in the navigation-channels, and where its floods produced a dangerous sea on the bar.

Mr. Hagen. Mr. L. HAGEN observed that the East Sea, or Baltic, extended from south to north over 12° latitude. In consequence of the greater warmth in the southern part, the surface of the water there was raised, and the water flowed off northwards along the eastern shore. The water flowing from north to south to replace this kept to the Swedish shore. In this manner a circular current arose, which caused, along the south shore of the Baltic, from about Colberg onwards, a coast-current from west to east. With a strong east wind, an opposing current occasionally appeared, but the west to

Mr. Hagen.

east current was the ruling one, and caused movements of sand from west to east.

The deep indentations between Dantzic and Pillau, and again south of Memel, were closed by the sand going eastward along the shortest line, and thus were formed the Frische Haff and the Kurische Haff, which were separated from the sea by narrow sand-hills, the so-called "Nehrungen."

The openings by which the water of the rivers flowing into the "Haffs" escaped to the sea, were thus forced up to the north-east corner of the Haffs, where they formed the so-called Deeps. (Tiefe). At Pillau and Memel these deeps were secured by stone piers. In a similar manner the smaller indentations in the Pomeranian coast had been closed by the drifting of sand, and a large number of lagoons formed, connected with the Baltic by narrow deeps. In long-continued sea-winds, these deeps were closed by the sand which the waves threw upon the shore, and when the wind ceased had to be opened out artificially in order to bring about a speedy lowering of the water in the lagoon. The mouths of these deeps constantly worked eastward, until the waters of the lagoon, at a high flood, burst through the sand-bank and took the shortest route to the sea. The rivers flowing into the Frische Haff and Kurische Haff deposited their sediment in the Haff, so that usually at Pillau and Memel only clear water flowed out. The material which raised the bar in front of the deep was brought by the coast-current and by the wind, which blew the sand from the sand-hills lying to westward into the deep. To hinder this the sand must be prevented drifting; and this was done by planting the sand-hills with grasses (*Arundo arenaria*), and afterwards with pines in considerable quantities.

In order to maintain the necessary depth for shipping over the bar, the out-flowing stream had to be kept to a definite position. For this purpose the mouth of the opening was narrowed as much as possible, and one of the piers had an evenly-curved concave form, so that the stream, being led along it, was delivered from the harbour-mouth on a definite point of the bar. By means of the great out-flow of water caused every spring in North Germany by the melting of the snow, the channel was so much deepened that slight subsequent shallowings did not affect the shipping. But in very heavy storms sometimes great quantities of sand were driven into the fairway. If a strong fresh did not follow, dredgers had to be used.

The deep at Pillau was now permanently more than 23 feet, that at Memel more than 20 feet in the Haff, where the wave-

Mr. Hagen. motion was small. Where there was no definite shore-current, sediment was deposited at the mouths of the river, and the formation of deltas went on. Especially was this the case at the mouth of the Nogat, in the west corner of the Frische Haff.

The conditions at the mouth of the Vistula were curious. The coast-current was turned aside by the Hela peninsula, and only reached the coast again at the root of the Frische Nehrung, so that the mouth of the Vistula was not affected by the coast-current. The sand which the Vistula brought down with it at flood was deposited, forming islands in front of the mouth. Formerly this happened at the port of Neufahrwasser. The formation of land, and the changes which had occurred since 1646, were shown upon the accompanying illustrations (Figs. 6). After the breaking through of the Vistula at Neufahr, 4 miles east of Neufahrwasser, in 1840, the shallowing at Neufahrwasser ceased, while, as shown by Fig. 7, in front of the new mouth at Neufahr, islands, which increased from year to year, were formed. These islands consisted of sand, the mud being washed out and carried away by the waves.

In Further Pomerania four rivers, which drained an area of from 500 to 800 square miles, flowed direct into the Baltic, namely, the Persante at Colberg, the Wipper at Rügenwalde, the Stolpe at Stolpmünde, and the Leba at the town of Leba. There was no delta at any of these rivers, as the sediment was removed and carried eastward by the coast-current.

In the case of the Leba, the mouth, where no works had yet been carried out, in accordance with the conditions explained above, constantly moved eastward. The mouths of the other three rivers were continued seawards by moles. Formerly these moles were but short; they had, however, in the past ten years been considerably lengthened, and at the mouths of the Wipper and Stolpe roomy basins had been formed. Naturally this caused the shore-line to advance seaward. For a number of years, however, this advance had been very slight, so that without much dredging a depth of at least 13 feet was maintained in and outside the mouth of the harbour. Outside the Colberg harbour the depth was somewhat greater.

As the River Stolpe brought down large quantities of sand, a wide basin had been formed above the harbour, in which the sand was deposited. This basin was dredged out every year, space being thus cleared for a further deposit. In this manner the sand was prevented from passing into the harbour, its removal from which would be attended with inconvenience to the shipping.

The River Oder flowed into the Stettiner Haff, which was joined

Figs. 6.

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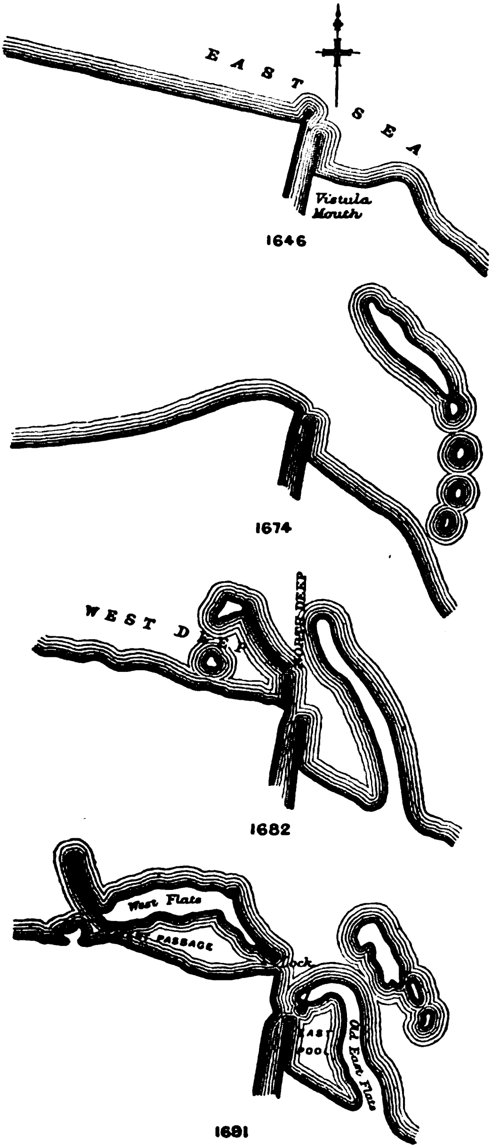

EAST SEA
Vistula Mouth
WEST DEEP
DEEP
West Flats
PASSAGE
Block
EAST POOL
Old East Flats

1646

1674

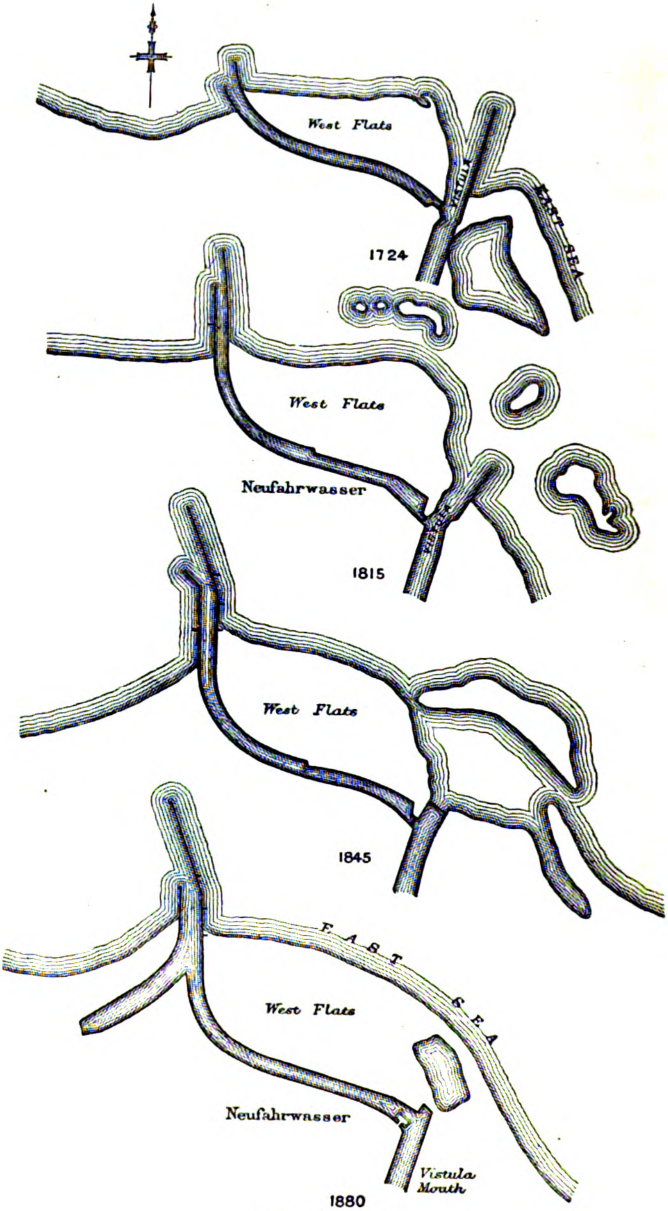
1682

1691

Scale 1 Inch = 1100 Yards.

Mr. Hagen.

Figs. 6.

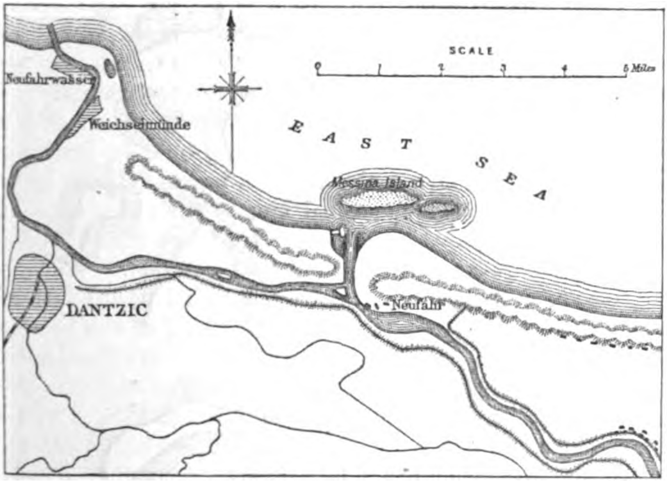

West Flats
Vistula
East Sea
1724
West Flats
Neufahrwasser
Vistula
1815
West Flats
1845
East Sea
West Flats
Neufahrwasser
Vistula Mouth
1880

Scale 1 Inch = 1100 Yards.

Mr. Hagen.

to the Baltic by three channels, the Peene, the Swine, and the Dievenow. The Swine was the chief of these, and at its mouth lay the harbour of Swinemünde, which had for sixty years been accessible to ships of 23 feet draught. The sediment brought down by the Oder was deposited in the Haff. As there was no definite coast-current in front of the harbour of Swinemünde, and as the outflow through the Swine was considerable, the above-mentioned depth was maintained without much dredging.

FIG. 7.



As the Author aptly observed, the mouth of rivers which flowed into the Baltic and Mediterranean lacked the powerful agency of flow and ebb, and on this account costly engineering works were generally necessary in order to maintain the needful depth for the shipping, and a sufficient cross-section for the passage of floods. The ports situated on the Baltic had, however, the advantage, not to be undervalued, of being accessible at all times, so that ships had not to wait the comparatively short time of high-water in order to be enabled to pass in or out.

Sir Robert Rawlinson.

Sir ROBERT RAWLINSON, C.B., observed that the Author stated broadly that tidal rivers had no true deltas, whilst non-tidal rivers were encumbered by them. These sweeping remarks had, however, only a limited application. There were tidal rivers which had outside banks and bars and vast accumulations brought down by floods and deposited, so as to choke the mouth of the rivers, and

Sir Robert Rawlinson. there were permanently deep-water harbours in non-tidal waters and seas, having neither bar nor delta, as the Golden Horn at Constantinople and the harbour of Sebastopol and Balaclava. The question of shoal-water or deep-water did not depend so much on rivers as on the surface formation and contour of the land bordering the sea, whether tidal or non-tidal. A flat swampy coast would, as a rule, have shoal-water; whilst a bold and rocky coast would have deep water; so that it might be taken that the visible shore-line would indicate the submerged coast-line sea-ward, as along the coast of Norway.

The Paper touched upon river-floods, which was one of the most important features to be studied. There were, however, floods and floods—annual and ordinary floods; with, at intervals, sometimes wide apart, exceptional floods; and it was these with which engineers should concern themselves. It might be taken as a rule without an exception, that Nature would sooner or later repeat excesses, and nothing man could do would prevent them. Excesses due to the elements were cosmical more than terrestrial. Heat from the sun evaporated the ocean water to be absorbed by the atmosphere for re-condensation and precipitation. When man could add to or reduce cosmical heat then he might add to or diminish river floods. Rivers were affected by floods in proportion to their geographical position, area, and surface contouring. The larger the area the less would be the flooding of the main rivers. But what were the excesses in some districts? In Australia rivers were said to rise 120 feet, and in South Africa 70 feet. In Great Britain and Ireland they rose from 20 to 30 feet. The lakes of Cumberland and of Killarney rose in flood from 10 to 13 feet.

The area of the Tiber was not much in excess of three of the English river areas; the Tiber had 6,455 square miles, the Thames 4,613 square miles, the Severn 4,350, and the Trent 4,052 square miles. The dry weather flow of these English rivers might not fall as low as in the Tiber, because the sources were not so elevated. Certainly the floods were not so great, but they were great enough to need attention leading to improvements. To control the floods in the Tiber, impounding reservoirs had been recommended; similar works had also been recommended for English rivers, but a few facts ought to dispel the idea. Impounding reservoirs on the Tiber or on any English river would have to be formed on the upper tributaries; and, consequently, could only have comparatively small capacities, which, if empty at the commencement of a wet season, a few days' heavy rain would fill, and then the reservoir might as well not be there, as, being full, it would be no further

Sir Robert Rawlinson.

available. The lakes of Cumberland were far larger in proportion to the areas above them than any artificial reservoirs it would be practicable to make on the Tiber or on the English rivers; and yet these lakes did not prevent flooding below them, nor seriously diminish it; as the lakes rose in flood until the discharge was equal to the inflow, and the water passed through them in volume almost equivalent to that flowing in. Areas such as the fresh water seas of North America, called lakes, most certainly did prevent flooding, and they probably afforded the only instance in the world of such action. It was said that the average discharge of water over the Falls of Niagara was about 20,000,000 cubic feet per minute, and that there was not much perceptible variation; but then the St. Lawrence had a drainage area of some 530,000 square miles or 339,200,000 acres, the volume of water in the river and lakes being more than one-half the fresh water on the globe.

One prime lesson to be learned from the Paper might be that a repetition of great floods must be anticipated and should be provided for. Dredging might do something, but embanking would have to be most relied upon, unless a new flood-water channel, commencing above Rome, was formed to the sea. Such a work would be costly, but it was practicable. Rome and the Tiber might under such conditions remain in harmony, excessive floods going to the sea through the artificial channel provided for these waters.

Mr. Ridings.

Mr. H. S. Ridings remarked that some interesting engineering work in connection with this subject had come under his personal observation in the year 1883 when he was engaged by the President of the State of Bolivar, South America, to survey the Dique mouth of the great Magdalena River and to report on necessary improvements. There had been a delta and bars of shifting sand at the mouths of this river for ages. At certain seasons steamers drawing 12 feet of water could enter the principal mouth; but as the channel was constantly changing and a formidable surf broke on the bar the navigation was perilous. As long ago as the year 1574 the Spanish Government took steps to overcome these difficulties, and to place the port of Cartagena, on the Caribbean sea, some distance to the north of the mouths of the Magdalena, in direct water communication with the great river. These objects were accomplished by cutting a canal from the river at a point about 100 miles above its mouth to the first of a series of large lagoons which were in some cases connected by natural channels, and where this was not the case channels were cut. Thus a

Mr. Ridings. continuous waterway nearly 100 miles in length was opened up to the harbour of the city of Cartagena, the capital of the state of Bolivar and at that time the most important city in South America. From 1574 to 1800 various Spanish Viceroys spent money on this channel, but apparently they did not maintain it in an efficient condition. From 1800 to 1825, during the wars of independence, this important waterway was totally neglected and became silted up in some parts and in others filled with dense masses of aquatic plants which completely prevented navigation. In 1825 the independence of the country having been assured, and war no longer engrossing the attention of the people, the Council of Cartagena undertook the improvement of the channel, but no substantial change for the better was effected till 1844, when the services of Colonel Totten, an American engineer, were secured. This gentleman laboured for six years at various improvements, but was not able to complete his scheme for want of funds. Within the last few years the government of the State of Bolivar had perceived the necessity of opening up traffic with the interior by means of large steamers, and dredging machines, similar in principle to the steam navvy, had been employed for deepening, widening, and in many parts straightening the Dique. Large numbers of piles had also been driven to maintain a definite course through the great lagoons and to keep back the growth of aquatic plants. Last year two large stern-wheel steamers were put together at Cartagena by Messrs. Yarrow, and had successfully navigated at high speed the Dique channel and the upper waters of the Magdalena for hundreds of miles, thus giving a fresh impetus to the trade of the ancient city.

Baron Siccama. Baron H. SICCAMA considered that the Tiber presented points of resemblance with the rivers Rhine and Maas, from where they left the higher banks to where the influence of the tide began to be felt. These rivers, too, varied greatly in the volumes of water discharged at different seasons, and flowed in the Netherlands through extended level tracts submerged during great floods. The extent of the inundation was diminished by embankments at some distance from and parallel to the course of the river, and in this way two beds were formed; one, the natural channel for the discharge of the usual summer flow, and the second, in most cases parallel to it, and of much greater width, but of less depth and sufficient in cross-section to contain the maximum discharge during the spring floods. The advantage of this system lay in the greater facility with which the summer river, so to call it, could be trained and kept to a straighter course, Baron Siccama.

than if it had room to meander over a broad and shallow bottom. The land, too, between the deeper channel and the embankments, only submerged during high floods, was at other times valuable as grazing ground. A further advantage of this system lay in raising the flood-level at the point where the river left the naturally high banks, thereby during floods decreasing the gradient above this point, and increasing the gradient below, with the same effect on the velocity of the current.

Where local circumstances did not admit of a roomy flood-channel parallel with and including the summer-channel, an overflow was provided for floods sideways over the low-lying land to a point where it could be returned to a natural channel. For instance on the Maas the flood-water left the river at Cuyk, and flowed over the low-lying meadows past Bois le Duc to rejoin the old mouth near Geertruidenberg. The Wahal branch of the Rhine discharged at high floods across the low lands near Heerewaarden into the Maas, relieving the narrow reaches lower down. These tracts of land were embanked to confine the inundation, kept free from obstructions and called "green rivers." In ordinary times they were used as grass lands.

On the Mississippi river the South Pass was sufficient for the dry weather discharge, and at the head of the passes the works were made so as to lead the usual flow as much as possible down to Port Eads, but the South-West Pass and the Pass à l'Outre were side-discharges for floods which might incommode the South Pass. Higher up no side-discharges were provided by art, and the levees were continuous, but from time to time the river escaped through crevasses to the lower bayous and the old creeks of its valley.

It might therefore be concluded that to free the city of Rome from liability to inundation through the insufficient capacity of the present bed of the River Tiber for the discharge of floods, it would be preferable if local circumstances admitted of carrying out the contemplated deviation as a "green river" of great width, but comparatively shallow and dry at ordinary times, rather than of forming a second deep but narrow channel, which would at all times discharge water, but in dry seasons would abstract more water than could be spared for the proper conservancy of the old bed. In lowering the usual level of the river at the city, the fall between that point and the mouth would be lessened, and he thought this would have a detrimental effect on the bed of that part. The distance to which the river-water was projected into the sea away from the mouth was dependent

Baron Siccama. on its velocity at the mouth, and therefore the gradient should be kept as great as possible in order that the solid matter carried in suspension by the river water might be spread over the greatest attainable surface of sea bottom, so as to give the littoral currents full scope to carry it away from the outfall. A high water-level, however, militated against the conditions necessary for drainage, and in this way the interests of drainage and navigation were at variance, and not easy to reconcile in practice.

Mr. Sutcliffe. Mr. G. W. SUTCLIFFE thought the subject had been treated much too exclusively from one point of view, so as to show that the all-powerful element or agency for keeping open a channel was a large volume of water operated upon by tidal agency. Sir Charles Lyell had given one fact after another to prove that the rivers in and near the basin of the Tiber were saturated with calcareous salts; so much so that they often deposited comparatively hard rock "travertin" at a rapid rate, and in a manner quite different from anything to be found in districts free from volcanic agency. There was absolutely nothing in the Paper to show that this aspect of the question had been considered. It was possible that the contact of this water with salt water might cause an instant precipitation of the calcareous matter; the state of cohesion of the precipitate proved nothing, as the deposit even from the fresh water varied in hardness with the weather and seasons. A simple experiment or two with test glasses would throw some light on this point, and also probably an analysis of the deposit would be useful. It did not follow that the presence or absence of tidal action regulated the absence or existence of a delta. Some were attached to tidal rivers, but nearly all were in parts of the globe which possessed a hot climate, and this might induce meteorological or organic conditions sufficient to account for the facts.

Probably a point might exist, at which a stream of water might hold in suspension as great a quantity of solid matter as it could transport, or in other words, it might reach a condition of mechanical saturation. Such a condition was, however, seldom if ever attained, and it might therefore be said that the transporting power of the current depended on its velocity. Therefore the relative velocities of current during the flood and ebb would prove most important factors to determine whether the tidal action, apart from upland-water, wind-action, and other incidentals, should be such as to cause scour or deposit. This might be illustrated by taking a high spring-tide in Kingroad, the total rise of which was about 46 feet. The flood occupied about four hours and three-quarters, and the ebb about seven

Mr. Sutcliffe.

hours and three-quarters. The quickest rise was at about half flood, and reached 13 feet per hour; the quickest fall at high ebb was only 7 feet per hour. Under these conditions the flood must obviously scour material to be deposited at time of slack water, and which the ebb was not competent to remove. The corresponding conditions applying to neap tides were very different in character. A tide, of which the total rise in Kingroad was only 15 feet, flowed about six hours and three-quarters and ebbed five hours and three-quarters; the quickest rise at half flood being 3 feet per hour, and the quickest fall at half ebb being about 3 feet 9 inches. In the latter case, though unfinished works in a tidal channel, and generally what migh tbe called dead-ends were covered by a thin coating of mud each tide, the trouble was as nothing in comparison with that attendant on spring tides, and the undisturbed banks of the channel tended slightly to scour. The deposit during spring-tides was so much greater than the scour during neaps, that the deposit accumulated until it was removed by fresh-water floods, after which the banks showed most clearly the results of the scouring-action. The greatest deposit took place in the region between ordinary low-water level and the level of heavy land floods. If tidal action were so universally powerful, there should be no tendency to flooding of lands or deposits of sewage mud in English river basins, as those of the Thames and Ouse; but if land-waters were so prone to cause trouble in their discharge, it followed that any English river would be sorely taxed to dispose of floods much less in quantity than those of the Tiber.

Each set of tidal conditions produced its own peculiar effects. These might be beneficial or otherwise. No universal rule was applicable. No one who had made practical acquaintance with the tides of the Bristol Channel would ever afterwards hold the opinion that no deposit took place; especially during spring-tides he would learn to respect them, but, perhaps, not to love them.

Mr. Vescovali.

Mr. A. VESCOVALI agreed with the Author's ideas about the regulation of tidal rivers. When a river of this class was canalized for the purpose of improving the navigation the flood-level at the head of the canal was sensibly lowered. The dry-weather flow (*acqua magra*) of the Tiber was 160 tons per second, not 100 tons as given in the Paper. It seemed certain that about two thousand years ago the river discharged into an ample basin at Ostia. Since that time the delta had advanced along the main channel a distance of 3¾ miles, or at the rate of about 3 metres (3·28 yards) per annum, while at Fiumicino the advance was now about 4 metres

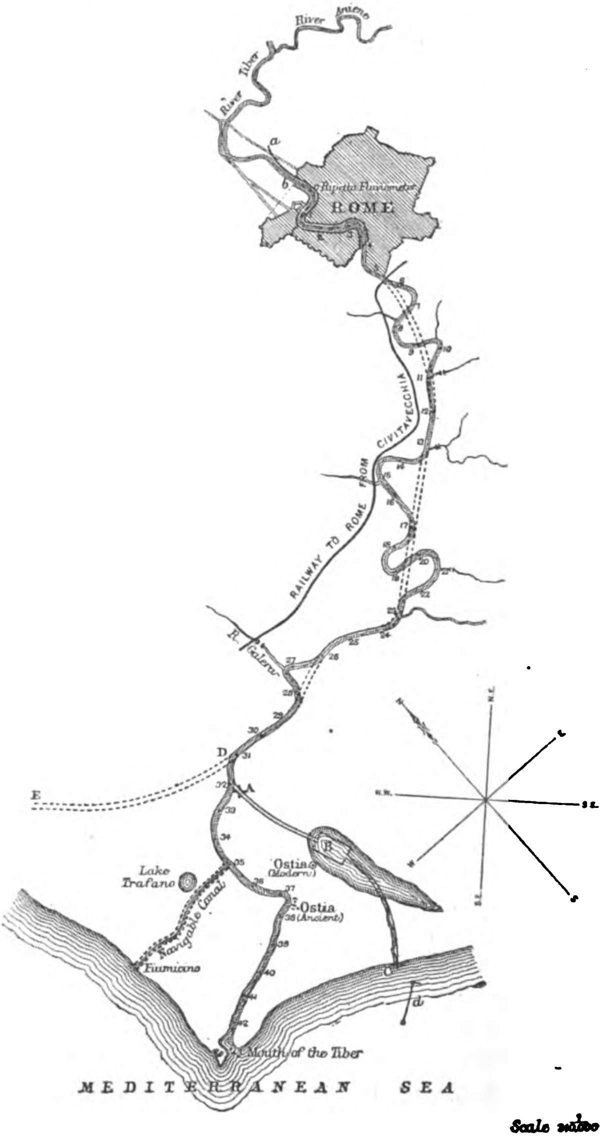
Mr. Vescovali. (4⅓ yards) per annum. In regard to the new works for the improvement of the river channel through Rome, he did not consider that the plan now in course of execution was the least expensive that could have been adopted; but that for the same outlay a more complete scheme might have been carried out. Nor did he think that the works, from an architectural point of view, would be satisfactory, because no steps had been taken to lower the floods, and they would therefore rise to the same height as in former years; hence the new bridges would have to be constructed at an inconveniently high level in order to pass the flood-waters, and this would involve considerable difficulty in raising the road approaches. He had always recommended that the channel should be straightened and improved rather than that the banks should be raised, the former plan being cheaper and involving fewer difficulties. The preservation of the city from floods demanded that the upper part of the river should be neither straightened nor embanked. The country above the city might well serve for a reservoir, and it was only the very highest floods (which were of rare occurrence) that could cause injury to the cultivated lands. The mud deposited from the Tiber was very fertilizing, and though, if too great a thickness was deposited, which very seldom happened, it might injure the crop of one year, that of the following year would be greatly increased. These lands were not artificially manured. He considered that the principle of "carrying low-water at sea as far inland as possible" might be applied to the Tiber with great advantage, as by this means, that was to say by straightening and canalizing the river, the ordinary low-water level in Rome would be reduced 13 feet, and a sectional area of 4,300 square feet would be obtained in the city below the present bed, and the effect of this would be to lower the flood-levels also. The Fiumicino canal, which was much narrower and deeper than the natural channel, was always kept open by the force of the current, and the only work necessary was to extend the timber moles at the entrance every two or three years as the shore lines advanced. In common with many of his friends and colleagues he entirely agreed with the views stated by the Author in the last paragraph of the Paper. Unfortunately the construction of the embankment walls in Rome was the only work which the government had sanctioned, and all the evil effects of this course would appear when too late to remedy them. The expense too was much greater than had been anticipated. He had no doubt that the effect of straightening and canalizing the river below Rome would facilitate navigation and diminish the flood-heights in

Mr. Vescovali.

the city, and he gave the following reasons for this view:—1st. That the river in that length had no tributaries of any importance. 2nd. That the bed consisted of homogeneous materials of the finest sand and clay. 3rd. That even at ordinary low-water (*acqua magra*) the minimum discharge was considerable, amounting to 160 tons per second. 4th. That if the river were properly systematized from Rome to the sea, the floods which occurred frequently throughout the year (except during the four summer months from June to September), and very frequently in winter, would produce nearly the same effect as the ebb of the tide in tidal rivers. The regulation of the Tiber would be perfected for the purposes of navigation by closing the natural mouth and diverting it into the Fiumicino canal, which would have to be enlarged; or by opening a canal D E (Fig. 8) across the marshes of Maccarese for the purpose of reclaiming them by warping, and by forming the navigable canal A B C, with a lock at A, a basin at B, mouth at C, and breakwater at *d*. The marsh of Ostia should be raised artificially. The engineer, Cesarini, had suggested in one of his memoirs that by contracting the low-water channel of the river (which was at present from 300 to 330 feet wide and less than 6½ feet deep) to 130 feet and increasing the depth to 16½ feet so as to preserve the same sectional area of 2,150 square feet, the mean natural velocity of the water (about 2¾ feet per second) would remain unaltered, and there would be a uniform surface-gradient of 0·10 metre per kilometre ($\frac{1}{10,000}$), which was much less than the mean of the present varying gradient, for the wetted perimeter would then be less and the mean radius greater. As the discharge of the Tiber was never less than from 5,600 to 6,300 cubic feet per second this would be sufficient to maintain the canal. Mr. Vescovali entirely concurred in this opinion, and considered that the hydraulic regulation of the Tiber ought to be carried out upon a combined system by canalizing from the commencement of the Fiumicino canal to the sea, and by straightening above the inlet of the Malafedi ditch, where the two great collecting sewers discharged, and carrying this systematization up to Rome, or better still to a point a little above the mouth of the Aniene, 5 miles above the city, where the works would terminate with two weirs built across the beds of the Tiber and the Aniene so as to prevent further erosion sending down more deposit. The effect of this would be to reduce low-water in Rome by 10 feet, and therefore the benches at the foot of the embankment walls might be placed 10 feet below their present position, or at the level of the existing bed, which was much higher than it was in ancient times.

Mr. Vescovali. The low-water level would then be lower than the existing bed, and this would give an increased sectional area of from 3,200 to 4,300

FIG. 8.


River Aniene
River Tiber
River Tiber
a
b
Ripetta Fluviometer
ROME
RAILWAY TO ROME FROM CIVITAVECCHIA
R. Galera
D
A
E
B
C
d
Lake Trafano
Navigable Canal
Fiumicino
Ostia (Modern)
Ostia (Ancient)
Mouth of the Tiber
MEDITERRANEAN SEA
N.E.
N.W.
E
S.E.
S
W
S.W.
Scale

square feet for the flood-waters. If this system had been carried out at first there would have been the further advantage that the new bridges would have had much better approaches. The lowering and confining of the low water would be of great advantage to navigation and to the drainage of the country, while the lowering of the flood-levels was most desirable for the safety and salubrity of Rome. In regard to the improvement of the marshes of Ostia and Maccarese, which were to be drained by pumping, like the Dutch polders, Mr. Vescovali would have preferred the adoption of the old Italian method of warping, or raising the land by deposits from the muddy waters of the Tiber which during floods carried to the sea an immense quantity of detritus. Fig. 8 showed what ought to be done. Two canals, A B C and D E, should be opened, which would serve to distribute the turbid waters over the marshes of Ostia and Maccarese, and would thus raise the level of those marshes. When this had been effected, the canal A B C would serve as a navigable channel. This sea-water canal would have the advantage of having its mouth C to the windward of the natural mouth of the Tiber, for the prevailing wind upon the coast was south-east, the head wind was south-west, and the littoral current ran from east to west. The depth of the sea at this point was naturally 16½ feet. The existing Fiumicino canal would become useless and might be abandoned, but it would be better to widen it and make it the principal mouth of the river by diverting into it the channel which now passed through Ostia, for in that way the mouth of the river would be removed further from that of the navigable canal, and the quantity of sand which the sea would carry to the latter under the action of the west and south-west winds would be diminished. Mr. Vescovali.

Mr. Shelford. Mr. SHELFORD, in reply to the correspondence, thought that Mr. Atkinson would not expect him to deal with the peculiarities of the Parret, of which he knew little. On the general question of the deposit of detritus he was of opinion that where the maximum velocity of the ebb tide was less than that of the flood the river would silt up, and that where the ebb tide (in which he included land-water) predominated the channel would be maintained; that the efforts of the flood tide to enter the river, and of the ebb tide to retire by the shortest route, tended to straighten the course, and thus to make the balance in favour of the ebb tide. There were many apparent exceptions which did not alter the principle, but which should be studied in its light. Sir Robert Rawlinson's adverse opinion of impounding reservoirs to intercept floods agreed with that of the Italian engineers, and was confirmed by the

Mr. Shelford. experience of the French. Baron Siccama had hit upon the best mode of dealing with very varying flows in non-tidal rivers, viz., by embanking, so as to form "green rivers," and in Garibaldi's proposed deviation of the Tiber this had been intended where possible. Plate 1, Fig. 4, showed that the principle had also been adopted in the works now constructing in Rome. He could not agree with Mr. Sutcliffe's theories as to the formation and occurrence of deltas. It was very gratifying to find that Mr. Vescovali, and many of his friends and colleagues, agreed with the views enunciated in the last paragraph of the Paper, because they had studied the subject in all its bearings in relation to the River Tiber. He was fully aware of the great difficulty in generalising on rivers, and had endeavoured to be guarded in his Paper. He had selected the Tiber as an illustration from many tideless rivers which he knew, because the information upon it was unusually complete and reliable, and he had been tempted to describe it in some respects more fully than was necessary for the immediate purpose, because he thought it enhanced the interest of the Paper.

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21 April, 1885.

GEORGE B. BRUCE, Vice-President,
in the Chair.

The discussion upon the Paper, "On Rivers Flowing into Tideless Seas, illustrated by the River Tiber," by Mr. W. Shelford, occupied the whole evening.

SPECIAL GENERAL MEETING.

28 April, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Notice convening the meeting was read:—

THE INSTITUTION OF CIVIL ENGINEERS.

Established 1818.—Incorporated by Royal Charter, 1828.

25, Great George Street, Westminster, S.W.

18th April, 1885.

The Council, considering it expedient to propose the enactment of certain new by-laws or regulations, and the alteration or repeal of certain existing by-laws or regulations, hereby summon a Special General Meeting of Corporate Members, to be held at the house of the Institution on Tuesday the 28th day of April, 1885, at 3.30 o'clock in the afternoon, to decide on the same. The term "Corporate Members" includes Members, Associate Members, Associates elected previous to the 2nd of December, 1878, and Honorary Members, all of whom will be entitled to be present, to take part in the proceedings, and to vote.

The general tenour and objects of the new by-laws or regulations, and of the proposed alterations or repeals, are as under:—

1. To carry out the recommendation of the Council, which was approved at the last Annual General Meeting, for altering the day for holding the Annual General Meeting in future. *See Section V.* (to become VI.), cl. 2; *Section IX.*, cl. 5; *Section XII.*, clauses 1, 3, and 4.
2. To render the by-laws as to the qualifications of the several classes of Candidates more consistent one with another: *See Section II.*, cl. 2 (paras. 2 and 3), cl. 4 (paras. 2 and 3), cl. 7; also *Appendix*, Form A2.
3. To make clearer certain passages: *See Section II.*, clauses 2 and 4; *Section III.*, clauses 3, 5, and 9; *Section VI.* (to become V.), clauses 1, 6, and 10; *Section V.* (to become VI.), cl. 2 (para. 2), cl. 3; *Section IX.*, cl. 1; *Section XII.*, cl. 9; *Section XIV.*, cl. 2; also *Appendix*, Forms C, E, E 1, G, I, and K.

The details of the proposed changes in the by-laws or regulations are shown in the printed copy accompanying this summons, to which the Royal Charter of Incorporation has been prefixed for facility of reference.

By Order,

JAMES FORREST, *Secretary.*

The President having explained the reasons which had induced the Council to recommend the proposed alterations, concluded by moving the following resolution:—

OBJECT I.

That the Annual General Meeting be in future held on the last Tuesday in May, unless that Tuesday shall be Whitsun Tuesday, in which case the Annual General Meeting shall take place on the first Tuesday in June; and that to effect this change the alterations proposed in Section V. (which will become VI.), cl. 2; Section IX., cl. 5; and Section XII., clauses 1, 3, and 4, be approved, such alterations being as under, the words proposed to be omitted being erased, and those proposed to be added being in italics:—

Sect. V. (to become VI.), cl. 2. At the Ordinary Meeting [~~on the Tuesday~~] *next but one* before the Annual General Meeting, the Council shall present a list of persons whom they nominate as suitable for the offices of President, Vice-Presidents, and other members of Council for the ensuing year. The list shall contain the names of at least twenty-nine Corporate Members, and shall be the balloting list for the annual election on the [~~Tuesday previous to Christmas Eve~~] *last Tuesday in May, unless that Tuesday shall be Whitsun Tuesday, in which case the annual election shall take place on the first Tuesday in June.* The names of persons proposed for the Council—other than the President and the four Vice-Presidents—shall all be printed in the same character of type, and in alphabetical order.

Sect. IX., cl. 5. A statement of the funds of the Institution, and of the receipts and payments during the past year, terminating on the [~~30th of November~~] 31*st of March*, shall be made, under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

Sect. XII., cl. 1. The Session of the Institution shall commence annually on the second Tuesday in November, and *shall* continue till the end of May, *but in case the last Tuesday in May shall be Whitsun Tuesday, then (as hereinbefore and as hereinafter stated) for the purpose of holding the Annual General Meeting, it shall continue till the first Tuesday in June;* and it shall be in the power of the Council to protract the Session, if it appear advisable.

Sect. XII., cl. 3. The Annual General Meeting of the Institution shall be held on the [~~Tuesday previous to Christmas Eve~~] *last Tuesday in May, unless that Tuesday shall be Whitsun Tuesday, in which case it shall be held on the first Tuesday in June*, at eight o'clock in the evening, to receive and deliberate upon the Report of the Council on the state of the Institution, with the annual statement of the Accounts, and to elect the Council and Officers for the ensuing year.

Sect. XII., cl. 4. The Ordinary Meetings shall be held on every Tuesday during the Session, at eight o'clock in the evening, with the exception of the Tuesdays between the [~~Annual General Meeting~~] *Tuesday previous to Christmas Eve* and the second Tuesday in January, *and also with the exception of Easter Tuesday and Whitsun Tuesday;* but it shall be in the power of any Ordinary Meeting, on the recommendation of the Council, to make such other exceptions as may appear advisable. No new question shall be introduced, or motion be made, after ten o'clock.

The Resolution was seconded by Mr. Woods, the senior Vice-President, and, after discussion, was unanimously agreed to.

OBJECT II.

The President then stated the reasons which had led the Council to think certain alterations advisable in the By-Laws defining the qualifications of the several classes composing the Institution, and moved the following Resolution:—

That to render the By-Laws as to the qualifications of the several classes of Candidates more consistent one with another, the following alterations be approved, viz.:—

Sect. II., cl. 2 (paras. 2 and 3).—He shall have been regularly educated as a Civil Engineer according to the usual routine of pupilage, and have had subsequent employment for at least five years, *and shall be actually engaged at the time of his application for election*, in responsible situations as Resident Engineer, or otherwise, in some of the branches defined by the Charter as constituting the profession of a Civil Engineer; or,

He shall have practised on his own account in the profession of a Civil Engineer for at least five years, and *shall* have acquired a considerable degree of eminence in the same.

Sect. II., cl. 4 (paras. 2 and 3).—Every candidate for election into the class of Associates entitled to the privileges of Corporate Membership shall be more than twenty-five years of age, shall have been regularly educated as a Civil Engineer, and *shall* be actually engaged *at the time of his application for election*, in the design or *in* the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter; *or*,

He shall satisfy the Council that he has had a sufficient training, and that he has been engaged for at least five years, and that he is actually engaged at the time of his application for election, in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter.

Sect. II., cl. 7. STUDENTS shall be persons not under eighteen years of age, who are, or have been, pupils of Corporate Members of the Institution, and who have the object or intention of becoming [~~Civil Engineers~~] *engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter;* and such persons may continue Students until they attain the age of twenty-six years, but not longer.

APPENDIX, FORM A 2.

(Student.)

A______ B______ of______________________________

______________________________ born on the______________________ day of______ 18___, being desirous of admission as a Student of THE INSTITUTION OF CIVIL ENGINEERS, I recommend him, from PERSONAL KNOWLEDGE, as worthy of that privilege, and as coming within the Rules appertaining to that class, viz.: that he is upwards of eighteen years of age, and is under twenty-five years of age, and is, or has been, *bonâ fide*, in the course of preparation and training under me, with the object of [~~following the profession of a Civil Engineer~~]

becoming engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter.

____________________ Signature of the Proposer, who must be a Corporate Member of the Institution.

____________________ Signature of the Candidate.

Dated this ______ day of ______________ 188__.

The Council, having considered the above recommendation, admit __________ ______________________________ as a Student of THE INSTITUTION OF CIVIL ENGINEERS.

Signed, ____________________
Chairman.

Dated this ______ day of ______________ 188 .

This Resolution was likewise seconded by Mr. Woods, and after discussion was unanimously agreed to.

OBJECT III.

The President next proposed that the By-Laws, Sect. VI. (to become V.), cl. 1 and 2, be altered as under:—

1. Those Members, Associates, and Students, [~~who reside~~] *whose place of business or whose residence is* within ten miles of the General Post Office, shall be considered Residents, and those beyond such limits Non-Residents.

2. On change of *place of business or of* residence, so as to go beyond or come within those limits before each annual contribution becomes due, the amount thereof shall vary accordingly.

This Resolution having been seconded by Mr. Woods, was unanimously agreed to.

The President then moved, and Mr. Woods seconded—

That the alteration shown in Section V. (to become VI.) cl. 3, be approved, viz., that for the words "not exceed," the words "be, without the repetition of any of them," be substituted, as shown in the following extract:—

Sect. V. (to become VI.) cl. 3. At the Annual election, each Corporate Member may erase any name or names from the balloting list, and may substitute the name or names of any other person or persons eligible for each respective office; but the number of names on the list, after such erasure or substitution, must [~~not exceed~~] *be, without the repetition of any of them,* the number to be elected to the respective offices as above enumerated. Those lists which do not accord with these directions shall be rejected by the Scrutineers.

This Resolution was unanimously agreed to.

The President stated that all the other matters were purely verbal. He would now formally move

That to make clearer certain passages the following alterations be adopted:—

Sect. II., cl. 2. MEMBERS shall comprise every person, other than an Associate or an Honorary Member, who [~~at the date of the passing of these By-Laws is~~] *on the 2nd of December* 1878, *was* on the Register as a Member; and every person thereafter elected or transferred into the class of Members. Every Candidate for election or transfer into the class of Members shall be more than twenty-five years of age, and come within one of the following conditions:—

Sect. II., cl. 4. ASSOCIATES ENTITLED TO THE PRIVILEGES OF CORPORATE MEMBERSHIP shall comprise every person who [~~at the date of the passing of these By-Laws is~~] *on the 2nd of December* 1878, *was* on the Register as an Associate and every person thereafter elected into the class of Associates, entitled to the privileges of Corporate Membership.

Sect. II., cl. 9. Any Member, Associate being a Corporate Member, Associate, Honorary Member, or Student, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs, according to the following abbreviated forms, *viz.* M. Inst. C.E., Assoc. M. Inst. C.E., Assoc. Inst. C.E., Hon. M. Inst. C.E., Stud. Inst. C.E.: it being understood that those Associates on the Register [~~at the date of the passing of these By-Laws~~] *on the 2nd of December*, 1878, who are Civil Engineers by profession, and those Associates thereafter elected to the privileges of Corporate Membership, shall alone be entitled to use the abbreviated form Assoc. M. Inst. C.E.

Sect. III., cl. 3. Any person whose proposal has been passed by the Council shall be duly informed of it by a letter, according to Form C., enclosing an engagement (Form D.) [~~to abide by the Charter, and By-Laws and Regulations of the Institution, if elected~~]; and he shall not be put up for ballot until he shall have returned the engagement (Form D.) with his signature appended.

Sect. III., cl. [~~5. The proportion of votes for deciding the election of any candidate shall be at least four-fifths of the numbers voting.~~]

Sect. III., cl. 5. *Every candidate shall be declared to be elected unless there be at least one negative vote for every four affirmative votes.*

Sect. III., cl. 9. Any person duly elected a Member, Associate, or Honorary Member, or transferred from one class to another, shall be informed thereof without delay, by a letter, according to the Form E., enclosing a promise (Form F.) [~~to abide by the Charter, and By-Laws and Regulations of the Institution~~], which promise the person elected or transferred must sign and return to the Secretary, and he must pay the admission fee and annual subscription for the current year (or the increase thereof in case of transfer) within two months after the date of his election or transfer, which otherwise shall become void; but the Council may in particular cases extend the time.

That the present Section V., "Election of Council and Officers," do become Section VI., and the present Section VI., "Contributions to the Funds," become Section V.

Sect. VI. (to become V.), cl. 6. Every new Member and Associate shall *on admission to the Institution* pay [~~on admission~~] *a* fee of ten guineas; *but no payment, other than the increased annual subscription, shall be due from an Associate on his transfer to Membership.*

Sect. VI. (to become V.), cl. 10. Any person whose subscription is two years in arrear, that is to say, whose arrears and current subscription shall not have been paid on or before the first of [~~March~~] *April*, shall be reported to the Council, who shall direct application to be made to him according to Form I.; and in the event of its continuing one month in arrear, after such application, the Council shall have the power, after suitable remonstrance, by letter, in the form so provided (Form K), of erasing the name of the defaulter from the Register or lists of the Institution.

Sect. V. (to become VI.), cl. 2 (para. 2). No person shall be nominated for the office of President more than two years consecutively, and at the expiration of such two years he shall not *for a period of three years* be eligible to be nominated for that office [~~for the period of three years~~].

APPENDIX, FORM C.

SIR, *The Institution of Civil Engineers,*

____________, 188___.

I beg to inform you that, having been proposed by Mr. ____________, and seconded by Messrs. ____________, your name was laid before the Council and passed as ____________ of the Institution, and was approved by the Ordinary Meeting of the Institution on Tuesday ____________. Previously, however, to your proposal being submitted to Ballot at the Meeting on Tuesday ____________ you are required to sign and return the accompanying engagement.

I beg to transmit to you a copy of the Charter, and of the By-Laws and Regulations of the Institution. The result of the Ballot [~~shall~~] *will* be communicated to you, immediately after the Meeting.

I am, Sir, &c.

And that in Sect. IX., cl. 1, for V. read VI., and in Sect. XII., cl. 9, Sect. XIV. cl. 2, and in the Appendix, Forms E, E 1, G, I and K, for VI. read V.

These several propositions, having been seconded by Mr. Woods, were unanimously agreed to.

On the motion of Mr. Fowler, Past-President, seconded by Sir Charles Hutton Gregory, K.C.M.G., Past-President, a vote of thanks was passed by acclamation to the President for his valuable services.

28 April, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President,
in the Chair.

(*Paper No. 2063.*)

"Mechanical Integrators."

By Professor Henry Selby Hele Shaw, Assoc. M. Inst. C.E.

All measurements are made in terms of some fixed unit. The method may consist of a simple comparison of the unit with the quantity to be measured, but when this cannot conveniently be done some indirect means must be employed. Indirect measurements may be made by measuring some physical effect the magnitude of which is known to be a function of the quantity to be measured, as for instance when the length of a rod or wire is estimated by its weight. Where, however, the unit in terms of which the measurement has to be made is what is known as a derived unit, the indirect method generally consists in measuring in terms of the simple units from which the former is derived and performing, with the results, the necessary calculation. An example of this latter method is given in obtaining the contents of an area by taking its length and breadth and multiplying them together, instead of adopting the tedious process of ascertaining, by direct comparison, how many times the unit of area would be contained within it.

Now such calculations, even when of so simple a kind as mere multiplication, often become very inconvenient, and a large number of instruments have been designed for performing them by mechanical means. Such instruments may be divided into two classes: one in which the final result of conditions which vary in an arbitrary manner is found, such as the contents of a surface or the work of a motor, requiring a process of multiplication or addition; the other in which the relation or ratio at any instant of two such quantities is given, such as space and time in the case of velocity, requiring at each instant a process of division. The object of the present Paper is to deal with the theory, design, and practical applications to engineering problems of the former class alone. It may be briefly stated that very little has yet been practically done in the use of the latter. Quite recently Professor A. W. Harlacher, of Prague, has published an account of the instruments and methods of Harlacher, Henneberg, and Smreker,[1] for gauging the velocity of a river current, the principle of which is the same as that independently adopted by the Author[2] and others in this country.[3]

The conditions or data above referred to, from which the required result has to be calculated by instrumental means, are obtained in two ways:—

(1) By intermittent or separate observations and measurements.

(2) By the continuous motion of a machine in connection with self-recording apparatus.

The former is the case in measuring an area of country, taking dimensions of a river or embankment section, or obtaining the forces exerted at different times by a machine or body in motion. The latter is generally given in the form of a graphic record, an important example of which is the diagram of energy or work taken from a prime mover. In both cases the result, whatever it be, whether boundary, area, volume, work, &c., can be found by calculation, but only with an approximation to the truth depending upon the extent of the calculation. The reason of this is that the data of calculation, which are taken directly in the first case or selected from the graphic record in the second, only represent actual conditions more or less closely, according as the number of data so taken is greater or less, and the greater the number the greater is the labour of determining the result. The instruments discussed in this Paper perform such work mechanically,[4] with the great advantages of rapidity of operation, accuracy of results, and without requiring mental effort on the part of the manipulator; and all this, moreover, to a great extent independently of the complexity of the calculation required. All the results, the measurement of which will be considered, can be represented graphically. If the observations have been made separately they can be plotted whether in the form of a diagram of energy, or on the plan or elevation of an area or section, and the boundary can be filled in with a tolerably close approximation to accuracy. In the other case the graphic record is, or may be, directly given. The subject, as far as the theory of the calculation goes, can therefore be studied with reference to such diagrams without the necessity of considering in the first case how they were obtained, and it will be convenient to do this, and afterwards to examine separately various examples of their application. Such diagrams may be drawn upon any kind of surface, and an instrument for dealing with measurements upon that of a sphere will be hereafter described. A plane surface may, however, be employed upon which to represent all cases of any practical importance, and the question thus arises—What are the measurements of the nature under consideration which are required, and which can be obtained from either a regular or an irregular plane of figure?

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[1] Technische Blätter, vol. xvi., part i., 1884.

[2] Proceedings of the Royal Society, p. 190, No. 232, 1884.

[3] Proceedings of the Physical Society of London, vol. vi., p. 147.

[4] These instruments do not include such appliances as the computer, used in Ordnance survey work, and elsewhere, which is really a slide-rule to simplify the calculations required in the approximate method.

Such measurements are of three kinds:

(1) The length of its perimeter or boundary.

(2) The area of its superficial contents.

(3) Its relation to some point line or other figure on the surface, *e.g.*, its moment of area or moment of inertia about a given line.

All these three kinds of quantities can be ascertained by successive operations of addition. The first requires the addition of elements of length, the second may be obtained by adding up successive elements in the form of strips of area, and the third by adding products obtained by multiplying such strips by some quantity, the magnitude of which depends upon the position of the other point, line, or figure in question. Taking the general case of an irregular figure, it is evident that absolute accuracy can only be obtained when this operation becomes that of integration or summing-up of an infinite series of indefinitely small quantities. Instruments for performing this operation are therefore called "mechanical integrators." In all such instruments the rolling action of two surfaces in frictional contact is employed, for this, as will be hereafter seen, enables the conditions of motion to be continuously varied in a way which could not be effected by mere trains of wheel-work, such as form the mechanism of some kinds of calculating machines. This fact necessitates something more than a mere discussion of the mathematical principles upon which the calculations are performed, for though the action of an integrator may be absolutely correct as far as its theory of the performance of the calculation is concerned, yet there is always some instrumental error depending upon the rolling, and also, as will be seen, of the slipping of the two surfaces in frictional contact. This error may be exceedingly small, but it is a matter of great importance to ascertain its exact amount, and the subject will therefore be investigated at length under the heading "Limits of accuracy of Integrators," where an account will be also given of the experimental results of Professor Lorber of Leoben, Dr. William Tinter of Vienna, and Dr. A. Amsler of Schaffhausen. In this investigation it will be shown that when integrators are examined upon the mechanical principles of action, they are all found to belong to one of two classes.

(1) In which the surfaces in question slip over each other.

(2) In which only pure rolling motion of the surfaces is assumed to take place.

The significance of this mode of classification is that it not only leads to a clear understanding of the nature of the results to be expected from any particular instrument, and teaches the best method of manipulating it, with regard to its position relatively to the figure to be measured, but it also brings out prominently the mechanical principle upon which the inventor has relied, sometimes as it would appear unconsciously, for the accuracy of the results expected to be obtained.

It may be here remarked that the same principle, by which an integrator is employed to determine a result from an autographic record, may be applied directly to obtain a continuous result from the machine, or body in motion, such for instance as an ordinary dynamometer or dynamo-electric machine, from which the autographic record was obtained. Thus, after discussing the action of integrators for dealing with diagrams, it will only be necessary to consider the mechanical details of the instruments for direct application to a machine, and this will be done under the head of "Continuous Integrators."

Coming now to the consideration of the actual measurement of the three kinds of quantities, it will be found that the first is very simple, and in fact the only reason why it is not convenient to measure it, by comparing it with the unit of length in the ordinary way, is its continuous change of direction.

The only mechanical method of rectifying a curve, as it is called, that is obtaining its length as a right line, is by rolling a wheel along it. This wheel is connected with a suitable train of wheels for recording the total number of revolutions, and as the rolling circle of the first wheel is either a unit in length or contains a known relation to this unit, the length of the curve or boundary is given at once by the reading of the graduated wheels. The use of such instruments is very ancient, and Beckmann in his "History of Inventions" describes, amongst various odometers, one mentioned in the Tenth Book of Vitruvius. Such an instrument is made upon a small scale for use by a draughtsman, and in one form it is sometimes termed an "opisometer," in another form the chartometer or Wealemefna; it is also employed upon a large scale as a road or route measurer. The same principle has been employed in one of the latest forms of anemometer,[1] in which the plane of the wheel is always kept coincident with the direction of the wind, while its edge rolls in contact with the recording surface and measures the total travel of the wind. In this class falls the device suggested in a letter to "Nature,"[2] by Mr. V. Ventosa of Madrid, for continuously obtaining the N., E., S. and W. components of the wind, a device which was independently arrived at by the Author in connection with certain mathematical principles referred to hereafter.

The object of employing a rolling wheel is merely to enable the direction to be changed so as always to coincide with the curve to be measured, and the principle is therefore that of direct unit measurement or comparison. The foregoing instrument, which evidently belongs to the second class in which only rolling motion without slipping is supposed to take place, forms, however, one kind of mechanical integrator.

The measurement of the other two kinds of quantities is, as in the case of the first, a problem of addition; but instead of being the addition of an infinite number of infinitely short lines, an infinite number of continually changing magnitudes has to be added. This is the same both for instruments required in the second kind of measurement or "Area Planimeters," and those required in the third kind, or "Moment Planimeters." From the fact that the changing magnitudes referred to are simpler to deal with in the case of calculating the contents of areas than in finding their moments or any mathematical results of an equivalent kind, the discussion of the theory of the two above kinds of instruments is not the same, and will therefore be dealt with under two separate headings.

AREA PLANIMETERS.

The area of any plane figure, such as A B D E (Fig. 1), can be obtained in the following manner. Take any straight lines,

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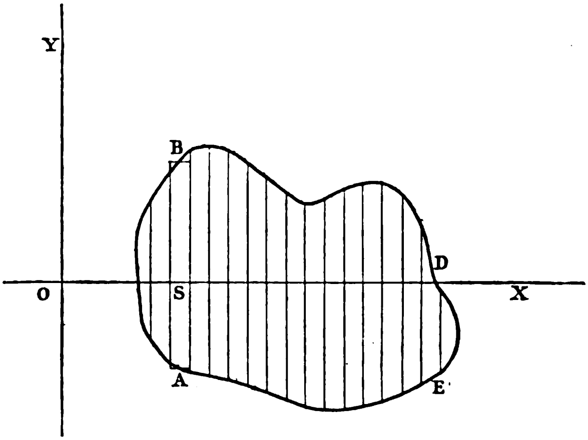
[1] "On a new Integrating Anemometer." By the Rev. J. M. Wilson, M.A., and H. S. Hele Shaw. Report of the British Association for the Advancement of Science, 1881, p. 543.

[2] Vol. xxv., p. 79.

O X and O Y, at right angles to each other, and parallel to O Y; draw a series of straight lines equidistant from each other, dividing the figure into a number of strips or elements of area. A series of rectangles may then be found, as shown at A B, the area of which is equal to that of the corresponding strip, so that by adding the rectangles together the area of the whole figure is obtained, as adopted in the common method of finding the area of an indicator-diagram. The greater the number of strips the more closely will the height of the two sides of each tend to become equal to each other, and to the height of the corresponding rectangle.

Fig. 1.



Let Δx = the width of any element of area such as A B, at a distance x from O.

y = height of the corresponding rectangle.

Then $y\Delta x$ = area of the element A B,

and the sum of all such elements of area is the area of the figure A B D E. When the number of elements is increased indefinitely, this expression becomes

$$\int_a^b y\,d\,x = \text{area of the figure A B D E},$$

a and b being the extreme values of x, *i.e.*, the limits of integration.

It is evident, therefore, that the area will be correctly measured by an instrument in which the recording wheel or measuring roller always turns at a rate proportional to the ordinate y of the curve, while the body from which it derives its motion moves at a uniform rate along the axis O X.

Area planimeters have been classified according to apparently different modes by which the operation of integration is performed; but since the action of them all can be explained upon the foregoing principle of adding elements of area, and, in fact, by means of the same notation, it is not surprising that such classifications are anything but satisfactory. In fact, in one important kind of planimeters, it becomes doubtful to which class they belong, or whether they should not be placed in two or more classes. It is without doubt very convenient to distinguish different planimeters, and therefore the names which have been given them will be used; but this will not denote any difference of principle, and the classification which will be adopted is that already explained, and depends on mechanical conditions of action. In what follows, one mode of viewing the mathematical operation is adhered to throughout, and it may be stated that the object of the Author has been to make clear the principles of action of integrators rather than to obtain rigid and exhaustive demonstrations of their theory, reference to authorities on the latter point being given in the foot-notes.

PLANIMETERS IN WHICH SLIPPING OF THE MEASURING ROLLER TAKES PLACE.

From a brief account of the subject by Professor Lorber,[1] it appears that the first recorded idea of a planimeter is attributed to Hermann of Munich, who worked it out with Lämmle. This idea of Hermann's, which was published in 1814, seems to have fallen into oblivion, for in 1827 Oppikofer of Berne constructed a planimeter upon similar principles, and it was thenceforth called after his name. On the other hand, Favora gives the priority to Professor T. Gonella of Florence, who in 1828, without any knowledge of what Hermann had done,[2] invented and described a very similar instrument. The development of the planimeter seems to have grown out of the instrument of Oppikofer, who, in conjunction with a Swiss mechanic, Ernst, finished a planimeter which won a prize in Paris in 1836. Important improvements are due to Wettli of Zurich, who, with Starke in 1849, took out a patent in Austria for the instruments now called the Wettli-Starke planimeter. Later on, in England, other inventors (Sang, Moseley) worked at the subject, but all these instruments depended for their action on the same principle, which is as follows:—

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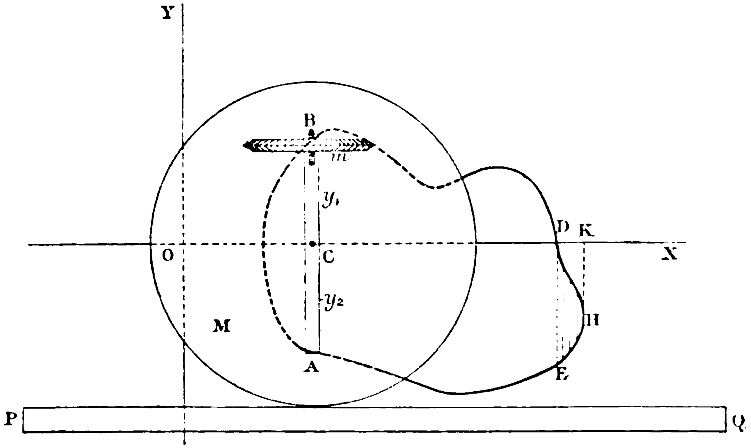
[1] "Ueber die Genauigkeit der Planimeter," von Franz Lorber. Oesterreichischen Zeitschrift für Berg- und Hüttenwesen, vol. xxxi., Jahrg. 1883.

[2] Reports by the Juries, Exhibition 1851, vol. ii., p. 664.

Let M (Fig. 2) be the plan of a disk rolling in contact with a straight guide PQ, which is parallel to O X, and at a distance from it equal to the radius of the disk, so that the plan of the centre of the latter always lies in O X. Let m be a roller upon the surface of the disk, graduated and connected with wheel-work and an index, so that the distance turned through over the surface of the disk can be read in revolutions or parts of a revolution. The plan of the point of contact (B) of the roller with the disk is always made to coincide with that particular point on the curve, which is in the line drawn at right angles to O X, through the centre C of the disk. The plane of rotation of (m) which may be called the measuring roller, is always perpendicular to the disk M, and the plan of its axis as shown in the figure, is always parallel to O Y, so that in following the curve it slips backwards or forwards across the surface of the disk, in a direction parallel to O Y. Suppose the disk to roll along P Q for a distance Δx, equal to the width of the element A B.

FIG. 2.



Then if y_1 = distance of B from O X.
R = radius of disk M.
r = radius of measuring roller m.
n_1 = consequent reading of measuring roller for this travel of disk.

Then $\frac{y_1}{R} \Delta x =$ linear distance turned through by a point on the disk at a distance y_1 from the centre.

$2 \pi r n_1 =$ linear distance turned through by a point on the circumference of m; but since m rolls on M these distances are equal.

Therefore
$$2 \pi r n_1 = \frac{y_1}{R} \Delta x,$$

or
$$n_1 = y_1 \Delta x \times \frac{1}{2 \pi r R};$$

but $\frac{1}{2 \pi r R}$ is a constant, which by taking r and R in suitable ratio may be made unity.

Then
$$n_1 = y_1 \Delta x,$$

that is, the reading of the roller m measures that part of the area of the element above O X.

If the point of contact be made to follow round the curve continuously in one direction, then when the portion of A B below O X is being measured, the disk is moving in the opposite direction along P Q, but at the same time the roller is turning in the opposite way relatively to the disk to that which it was doing before, since the point of contact is now below C. The final result of these two opposite motions is to cause the roller to turn as at first, and so add the result given for C A to what was given for C B. If the motion of the disk Δx for the width of A B be now regarded as negative,

and
$$- y_2 = \text{distance A C}$$

also $n_2 =$ reading of roller for this element of area.

Then by similar reasoning to that already used,

$$n_2 = (- y_2)(- \Delta x)$$
$$= y_2 \Delta x,$$

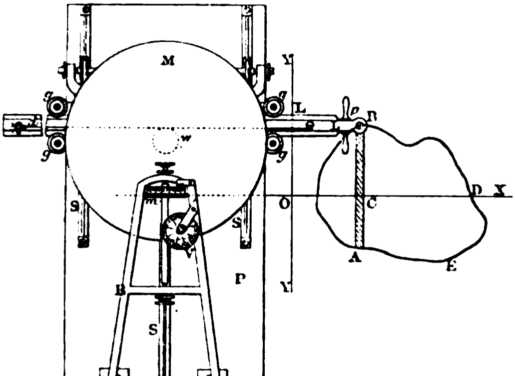
and
$$n = n_1 + n_2 = (y_1 + y_2) \Delta x = y \Delta x$$
$$= \text{area of element A B.}$$

This reasoning holds for any possible position of the roller or of the axis O X, which may be altogether outside the figure, as it practically is for the integration of the portion DHE. Then it will be found that DKH is subtracted, and DKHE is added so as to give the required actual area DHE.

Inasmuch as this reasoning is independent of the actual value of the width of the element, and as the vertical motion of the roller *m* has no effect in theory upon the distance rolled through by it, therefore in the limit when Δx becomes infinitely small, the actual value of the series of infinitely narrow strips which compose the figure ABDE is given by the final reading of the roller when the traverse of the boundary is completed.

The Wettli-Starke planimeter (Fig. 3) acts directly upon this principle, with the exception that it is the disk that is moved according to the changes in *y* instead of the measuring roller, and the following is a description of the best form of this instrument.

Fig. 3.



On a base-plate (P), Fig. 3, are three guides SSS, along which a frame carrying the vertical axis of the disk M can be moved to and fro. The disk, which is made of glass and covered with paper, has two motions, one rectilineal along the guides, and one of rotation about its axis. The motions are imparted to it by means of an arm (L), which passes through the roller-guides (*gg*) in the frame carrying the disk, and rotates the latter by means of a German silver wire (*dd*) passing round a cylinder *w* upon its axis, and attached by the two ends to the extremities of the arm. The measuring roller (*m*) rests upon the surface of the disk, being carried in another frame (B), which is hinged to the base-plate. The action is as follows:—The base-plate being placed in juxtaposition to the figure to be integrated, any line parallel to the guides, *i.e.*, to the direction of rectilinear motion of the disk, may be taken as the axis OY; and line OX, drawn through the edge of the roller, perpendicular to OY, may be taken as the other axis. Then, as the pointer p at the extremity of the arm is made to pass round the boundary of the figure, the disk will be turned through a distance proportional to the travel along OX, while at any instant the roller (m) is at the same distance from the centre of the disk as the pointer is from OX.

If $y_1 = \mathrm{C\,B} =$ mean height of element

$\Delta\, x =$ width of element A B.

Then, by the reasoning already given, the reading of the roller which the pointer passes over the upper boundary of the element AB, is

$$n_1 = y_1\, \Delta\, x,$$

and the final reading of the roller is

$$\mathrm{N} = \text{area of the figure A B D E.}$$

Hansen in 1850 still further improved this instrument, and, in conjunction with Ausfeld, introduced a different method of reading the result, and of carrying the frame, this instrument being known as the Hansen-Ausfeld planimeter. Various other instruments of the same kind were shown in the Great Exhibition of 1851, but in all, the motion of the arm carrying the pointer was "linear"; that is, the motion, which must be possible in every direction, is obtained by compounding two rectilinear movements at right angles to each other. Such instruments are therefore called "linear planimeters."

Many different forms of linear planimeters have been suggested, but the only modification of the disk and roller which it will be worth while to notice is the cone and roller.

Let MM′, Fig. 4 (p. 14), be the cone corresponding to the disk M, and rolling on the edge of its two bases in a direction parallel to OX. Let the roller m always be in contact with a circle on the cone, whose centre B′ is at a distance CB′ from the apex C of the cone, such that

$$\mathrm{C\,B'} = \mathrm{S\,B} = y = \text{mean ordinate of element S B.}$$

where the element AB is being at that instant integrated. Adopting the same notation as before, when the cone has rolled over the surface through a distance Δx, then, whatever be the angle of its apex, the distance rolled through by the roller m is

$$2 \pi r n_1 = \frac{y_1}{R} \Delta x,$$

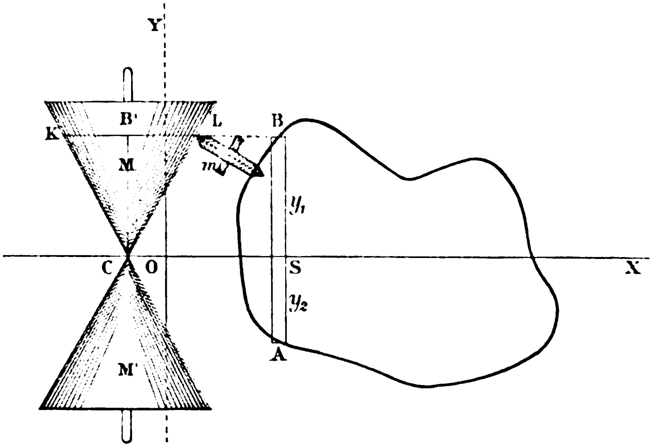
or

$$n_1 = y_1 \Delta x \times \frac{1}{2 \pi r R}.$$

As might have been anticipated, the expression is the same as was obtained in the case of the disk, the latter being a special case of the cone when the vertical angle is 180°.

Thus the cone may be employed instead of the disk, and such an instrument was invented by Mr. John Sang, who in 1852 published a description[1] of it, according to which the action was extremely accurate, but it does not appear to have come into very extensive use.

FIG. 4.



No more instruments of the kind will be described, since they have given place to those in which the arm carrying the pointer turns about a centre or pole, and which are therefore called "polar planimeters."

In the year 1856 Professor Amsler-Laffon invented and brought before the world the now well-known polar planimeter bearing his name, and since then no less than twelve thousand four hundred of these instruments have been made and sent out from his works at Schaffhausen. According to authorities,[1] which Professor Lorber quotes, Professor Miller, of Leoben, invented independently a planimeter of this kind in the same year (1856), which being made by Starke, of Vienna, is known as the Miller-Starke planimeter. Previous to this, in 1854, Decher, of Augsburg, as well as Bouniakovsky, of St. Petersburg (1855), had improved upon previously-existing forms of polar planimeter, though it is well to note that the planimeters already mentioned as sent to the Great Exhibition of 1851 from various parts of Europe, as Italy, Switzerland, France, and Prussia, were all linear, and no mention is made of polar planimeters in the jurors' report.

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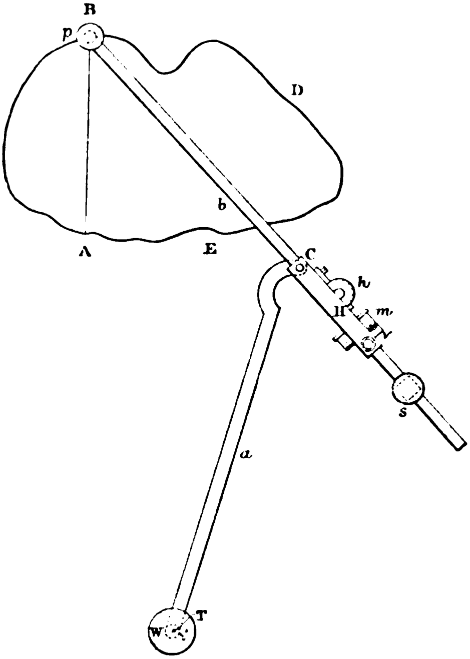
[1] Transactions of the Royal Scottish Society of Arts, vol. iv., p. 119.

Fig. 5.



The Amsler planimeter is shown in Fig. 5. It consists of two bars, (*a*) the radius bar, and (*b*) the pole-arm, jointed at the point C. The tracing point *p*, which now coincides with the point B of the figure A B D E, is carried round the curve, and the roller *m*, which partly rolls and partly slips, gives the area of the figure; and by means of the graduated dial *h*, and the vernier *v*, in connection with the roller *m*, the result is given correctly in four figures. The sleeve H can be placed in different positions along the pole-arm *b*, and fixed by a screw *s*, so as to give readings in different required units. A weight at W is placed upon the bar to keep the needle-point in its place, but in instruments by some other makers T is a pivot in a much larger weight, which rests on the paper. A recent minor improvement has been to fix a locking spring to[1] the frame, so that the roller can be held when the planimeter is raised for the purpose of reading it.

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[1] "Ueber die Genauigkeit der Planimeter," by Professor Lorber, p. 8.

FIG. 6A.

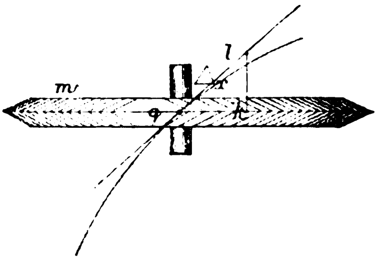
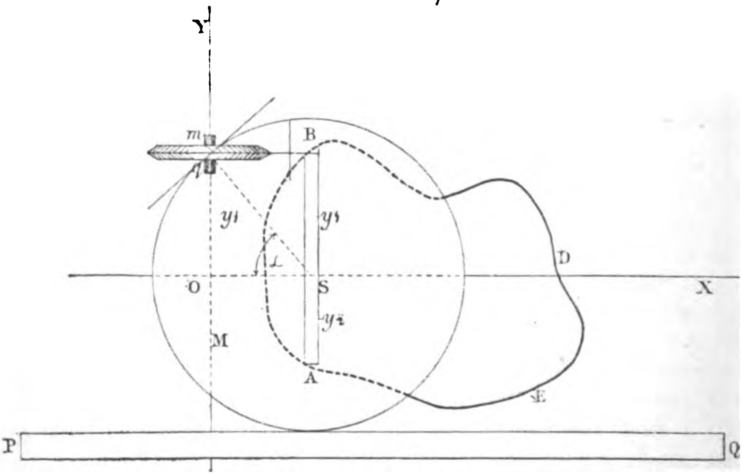


FIG. 6.



The theory of the polar planimeter may be simply deduced from that of the disk and roller thus:—

Let Fig. 6 represent the same disposition of the disk M with regard to the figure A B D E, as in Fig. 2, but now let the roller *m* move round the edge of the disk instead of across it, its distance from O X being always the same as before, viz.:—

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[1] "The Engineer," vol. lviii., p. 336.

$$\mathrm{O}\,q = \mathrm{S\,B} = y_1.$$

The turning of *m* for a given travel, $\Delta\, x$, of the disk is found thus, draw *lq* (Fig. 6 A) tangent to the disk at *m*, so that

$$lq = \Delta\, x,$$

and draw *l k* parallel to the axis of rotation of *m*, then *q k* is the distance turned through, and *l k* is that slipped through by the edge of the roller *m*, when the disk has rolled through a distance $\Delta\, x$; therefore, using the same notation as before,

$$q\,k = 2\,\pi\,r\,n_1$$

and $$\frac{q\,k}{l\,q} = \frac{2\,\pi\,r\,n_1}{\Delta\,x} = \sin \angle\, q\,l\,k;$$

but in Fig. 6 $$\frac{\mathrm{O}\,q}{\mathrm{S}\,q} = \frac{y_1}{\mathrm{R}} = \sin \mathrm{O\,S}\,q.$$

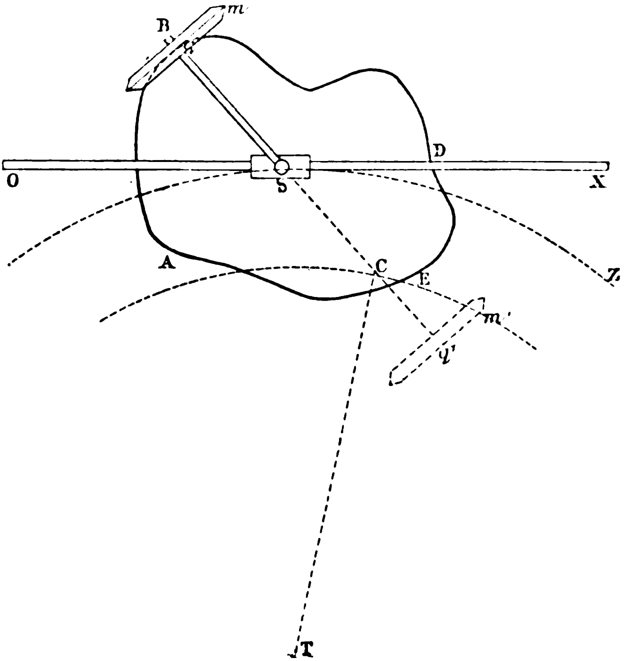
But by similar triangles $\angle\, q\,l\,k = \angle\, \mathrm{O\,S}\,q = a$;

therefore $$\frac{2\,\pi\,r\,n_1}{\Delta\,x} = \frac{y_1}{\mathrm{R}},$$

or $$n_1 = y_1\,\Delta\,x \times \frac{1}{2\,\pi\,r\,\mathrm{R}}.$$

This is the same result as previously obtained, and it has been given in this way because there is an important class of planimeters to be hereafter described, combining the polar planimeter with the disk and roller, in which a principle is employed which is thus made obvious. This principle is, that the turning of *m* is exactly the same as if it were in contact at the point B, no matter in what position it may be along the line through B parallel to O X. The turning of *m* thus measures the area of the element as long as *y* does not change. If, however, the value of *y* changes so that *m* changes its distance from O X, the measuring roller is likewise turned a certain additional amount from this cause; but this does not affect the correct reading of the area so long as its first and last positions are equally distant from O X. The reason is, that then the roller has turned as much in one direction in moving away from O X as it has in moving towards it, and this is the case for the initial and final positions of the pointer when the complete travel of the closed curve has been made. Now, inasmuch as the velocity of the edge of the disk is just the velocity at which the centre has been shown to move along O X, the disk may be removed altogether. The roller is then moved in contact with the surface of the figure, and with identically the same amount of turning as before, provided that its plane of rotation is turned so as to make the same angle with O X (which is now its direction of translation) as it did before with the direction of motion of the edge of the disk in contact with it. This is the case when it is turned through that angle, and then its axis of revolution coincides with the radius S q.

Fig. 7.

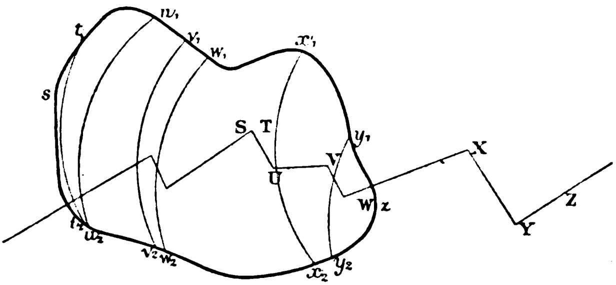


In order to keep the direction of the plane of rotation always at right angles, it is only necessary to have a rod or bar S q capable of turning on a pin at the point S. The pin at S is attached to a sleeve, which can freely move along a guide-bar, whose direction coincides with the axis O X. By employing the bar q S q^1 itself as the axis of rotation on which m turns, the simple planimeter shown in Fig. 7 is obtained, in which the point of contact of the measuring roller is made to pass round the diagram. The turning of the roller m correctly gives the superficial contents.

The roller can be moved to any position on the rod, such as shown in dotted lines, Fig. 7, without in any way affecting its resultant turning, and the former point of contact of the roller is replaced by a pointer, which is made to follow the curve instead of the roller. Professor Burkett Webb has described to the Author a planimeter of this form used in the United States known as "Coffin's" planimeter.

If, finally, the point S, instead of moving along the straight line O X, which may be considered as a portion of a circle with its centre infinitely distant, moves along the arc S Z (Fig. 7), or any other arc, as, for instance, that with radius T C, the instrument becomes the ordinary Amsler planimeter (shown in dotted lines).[1] This explanation so far is based upon that given by Sir Frederick Bramwell, who has further shown that the change from the motion in a straight path to that in the arc of a circle has no effect upon the ultimate reading when the complete travel round the closed curve has been made, and the arm S B has returned to its initial position. The following demonstration of the truth of this appears, however, to have an advantage, in that it follows throughout the operation of integration, especially as recent planimeters are more complicated than that of Amsler.

Fig. 8.



1st. Let point S (Fig. 8), at the extremity of the radius-rod, move along the broken line S T U V W X Y Z, and from these points draw arcs with a common radius = R, cutting the curve in points $t_1 t_2$, $u_1 u_2$, $v_1 v_2$, &c., s and z being tangent points at the end of the curve from the points S and Z. The proof has already been given that the integration of the complete portion $s t_1\ t_2$, taken separately, is given by the reading of the measuring-roller; so also are given the areas of the various other portions, $t_1\,u_1\,u_2\,t_2$, &c. If the separate portions were integrated consecutively, any arc, such as $t_1\,t_2$, would be traversed in both directions by the measuring-roller, because it would move one way round in traversing one figure and the opposite way in going round the adjacent one, and the reading due to the arc would be eliminated.

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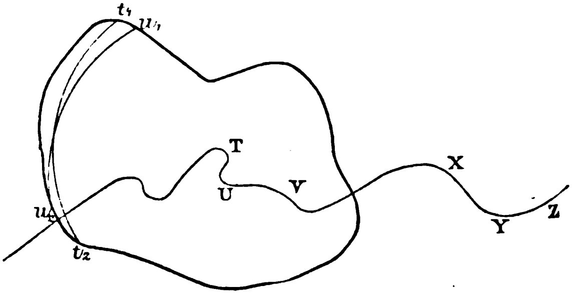
[1] "On Amsler's Planimeter." By F. J. Bramwell. Report of the British Association for the Advancement of Science, 1872, p. 401.

Thus the whole curve may be integrated correctly at once without going round each separate portion formed as above, even if the point S at the end of A B moves upon a broken line instead of along O X. Next, substitute a continuous curve T U V X Y Z (Fig. 8 A) for the broken line. This curve may be supposed to consist of an infinite number of straight portions. The infinitely small portions contained between an arc, as $u_1\,u_2$, and another very close to it, drawn from the beginning and end of these straight portions, may, just as in the case of the broken line, be supposed to be integrated separately and with a correct result, which is independent even of a possible crossing of the arcs, as $v_1\,v_2$ and $u_1\,u_2$. In the same way as before, it may be seen that the arcs $u_1\,u_2$, &c., need not be traversed, and, so long as the point S returns to its initial position, the area of the figure is given by the simple traverse of its boundary, whatever be the curve on which the point S moves, which, in the case of the Amsler planimeter, is a circular arc.

FIG. 8A.



Various writers[1] have explained the action of the simple polar planimeter in ways more or less different. One of these ways, recently given by Mr. F. Brooks, of Lowell, U.S., may be alluded to. He shows that the area may be treated as the difference between the area swept out by the line T p (Fig. 9) and the sector of the zero circle, or circle upon whose circumference the pointer (p) being moved, the measuring roller is not in consequence turned. This is true, both for the outside or inside, if proper signs be taken. Let the element of area $p\,q$ be passed over, the curve at p being for a small distance considered concentric

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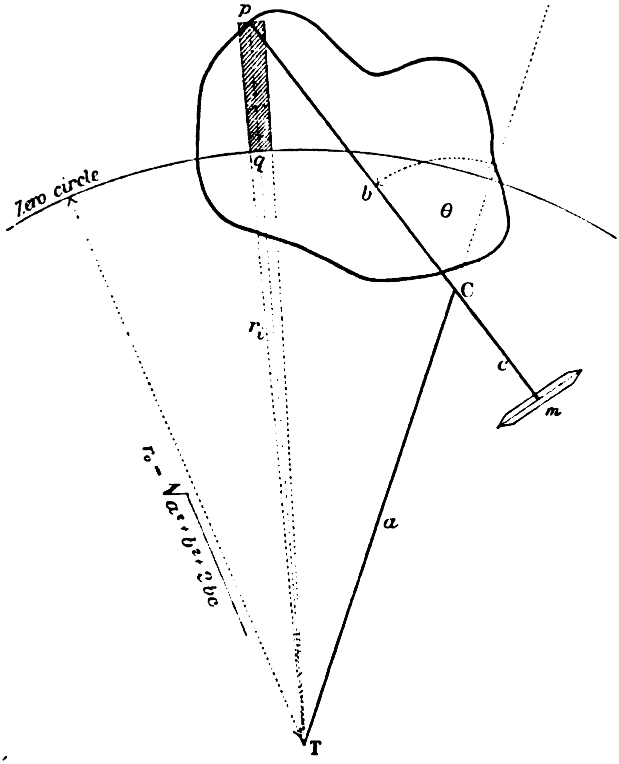
[1] Some of these in English are: "Integral Calculus," § 146, p. 203. Williamson. "Mathematical Instruments," vol. i., p. 80. By J. F. Heather. "Mechanics of Engineering," vol. ii., p. 69. By Dr. P. J. Weisbach. Report of the British Association for the Advancement of Science, 1880, p. 371. Journal of the Association of Engineering Societies, vol. iii., p. 294. Brooks.

FIG. 9.



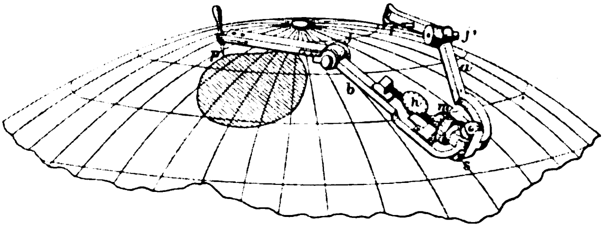
with the zero circle, this small area subtending an angle w at the centre; then if values be taken as shown upon Fig. 9, in which

C T = radius-bar = a;
C p = one portion of pole-arm = b;
C m = the other portion of pole-arm = c;

$$\text{Area } p\,q = \tfrac{1}{2}\,w\,(a^2 + b^2 + 2\,a\,b\cos\theta) - \tfrac{1}{2}\,w\,(a^2 + b^2 + 2\,c\,b)$$
$$= w\,b\,(a\cos\theta - c),$$

and by a geometrical construction the travel of the measuring roller is easily shown to be equal to the same expression. Mr. Brooks also explains why the area of the zero circle must be added to the reading if the figure to be integrated contains the centre T. The following appears, however, to be a still simpler explanation. Referring to Fig. 7, it is evident that going round the outside of the zero circle corresponds to a movement taken continuously above the zero line O X when only the portion above O X is measured. In this latter case the curve could never be completely traversed as long as the pointer moves in one direction. Suppose, however, that the ends of O X are bent round and brought within the figure, then the motion in one direction will enable the complete circuit to be made; but only the portion outside the line, *i.e.*, corresponding to that originally above O X, will be measured by the roller, and that within must consequently be added to the recorded result. This quantity is evidently the area of the zero circle in the case of the Amsler planimeter, which must therefore always be added to the result when the centre of the radius-arm is within the diagram to be measured.

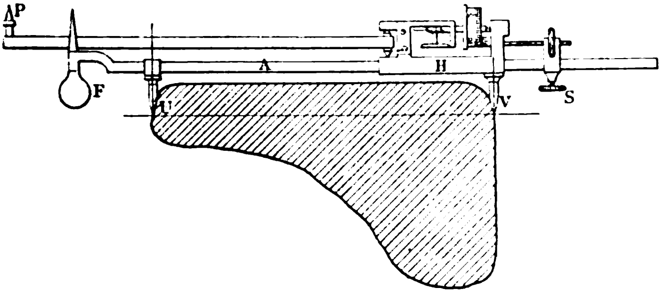
Fig. 10.



As the Amsler planimeter alone, so far as the Author is aware, has been modified to measure the area of any non-developable surface, this modification may be here noticed. The only surface of the kind to which it has been adapted is a spherical one. Fig. 10 shows the instrument, and from that figure it will be seen that the chief alteration is the placing of two joints *j j'*, one upon the radius bar (*a*), and the other upon the pole arm *b*, so as to allow the employment of the integrator for surfaces of varying curvature. The joints are equidistant from the end of each bar, and exactly opposite to each other—the radius-bar and pole-arm being now of equal length, and a pin *f* is placed on (*a*), which fits into a corresponding recess in (*b*), so that when the two arms are closed, they can be together bent at the joints to the required amount, and the joints being purposely made stiff, they will remain at the proper angle when the instrument is used. The joint (*j*) acts so that the tracing point (*p*) is always in the plane of the axis of rotation of the measuring roller. The theory of the action of this instrument has been fully explained by Professor Amsler,[1] in an article in which the theory of the relations between measurement upon a spherical surface and upon a plane surface is discussed.

The various applications of the simple planimeter for finding areas are well known, and need not be explained; but there are some slight modifications of the instrument for special purposes, and one of these recently applied by Professor Amsler to his planimeter is worth noticing. This is illustrated at Fig. 11, and is a device for reading at once the mean pressure given from an indicator diagram. Two points, U and V, are seen, one (U) being upon the upper side of the bar A, which slides in the tube H, and one (V) upon the tube H itself. These points can be adjusted to the length of the diagram by inverting the instrument in the way shown in the figure, and the sliding-bar is then clamped by the screw S. This setting causes the reading of the instrument, when the diagram is traversed by the pointer in the usual way, to give at once the mean height of the diagram in fortieths of an inch. The simple relation is as follows :—

FIG. 11.



$$\frac{\text{Reading of measuring-roller}}{40} = \text{Mean height of diagram in inches.}$$

$$\text{Mean pressure} = \text{Mean height} \times \text{vertical scale of diagram.}$$

As an instance of the great saving of labour by the use of the Amsler planimeter, the Author happens to know a civil engineer's office where a large amount of earthwork quantities had to be taken out. The calculations proceeded slowly and with many repetitions, until one of the draughtsmen procured a planimeter, and then the other; with the result of a great expedition of the work, and almost the complete absence of errors—and even then only in decimal places—where previously the divergence had been as much as by units.

---

[1] "Zeitschrift für Instrumentenkunde," 1884.

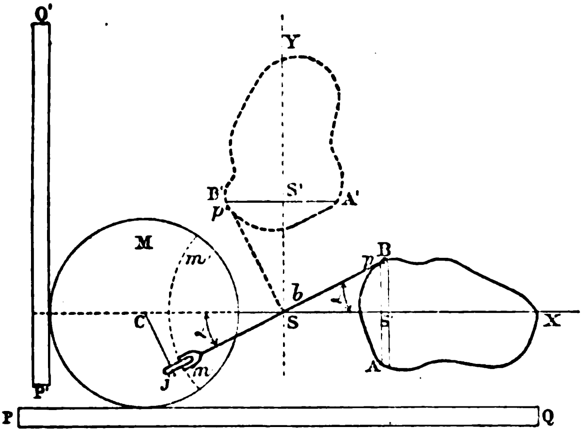
Although the connection between the disk and roller or linear planimeter and the polar planimeter has been shown, it is possible to regard them as acting upon different principles. The former may be considered as measuring the variation in the ordinate (y) by a change of effective radius of the circle on which the measuring-roller works, the latter measuring the same thing by a corresponding change in the sine of the angle which its plane of rotation makes, with its direction of motion over the surface on which it rolls. They have, in fact, been classified in this way as radius machines, and sine or cosine machines, for the slipping, although occurring in both, appears in the ordinary way of viewing the subject to affect the result in different ways.[1] In the former, slipping is supposed to be entirely due to the variation in the value of (y), and only takes place when the ordinate changes in value; in the latter the change is supposed to be effected by turning the pole-arm about its centre, without any slipping at all. This distinction is however quite an imaginary one, for it will be seen that if the curve be obliquely inclined in either case to the axis O X, the action of the measuring roller is precisely the same. Recently, a large number of what are called "Precision Polar Planimeters" have been designed and constructed, which combine in an obvious manner the above two principles of action, the disk giving motion to the roller, while the pole-arm carries it across the disk in an oblique direction. Thus the advantages of a uniform and invariable surface of contact for the roller, and the convenience of the polar planimeter are combined, with the still more important advantage of a large relative turning of the measuring roller. Before describing a few different forms of the best of these instruments, the general theory upon which they work will be given; it will then not be difficult to understand the action of the several instruments without repeating the explanation in each case. It will be found that both the linear and polar planimeter are only special cases of application of the general principle upon which the correctness of action of precision planimeters depends.

---

[1] "Philosophical Magazine," Feb. 1882, p. 77.

It will be well to approach the matter from the same point of view as in explaining the linear planimeter. Let the disk M, Fig. 12, rotate about an axis C as it rolls along the line P Q, parallel to O X, the pivot on the axle at C being attached to a frame which also carries another pivot S. This latter pivot always lies upon O X, and about it rotates a pole-arm *b*, carrying a pointer *p* at one end, and the measuring roller *m* at the other end. The plane of rotation of the measuring-roller coincides with the direction of the pole-arm, and is carried over the disk in contact with it, along the arc *m m'*. Then from what was proved, p. 17, the motion of the roller *m* is exactly the same as if it were moved, so that its axis always coincides with C *j*, the perpendicular upon the pole-arm from the centre of the disk—provided only that its axis is always parallel to this line. Thus, adopting the previous notation, and taking

FIG. 12.



S *p* = length of upper portion of pole-arm = R.
Then when the disk rolled through a distance $\Delta\, x$,

$$n_1 = \text{reading of roller } m$$
$$y_1 = \text{ordinate S B.}$$

$$\frac{\text{turning of roller}}{\text{distance turned by edge}} = \frac{2\,\pi\, r\, n_1}{\Delta\, x} = \frac{C\, j}{C\, S} = \sin a;$$

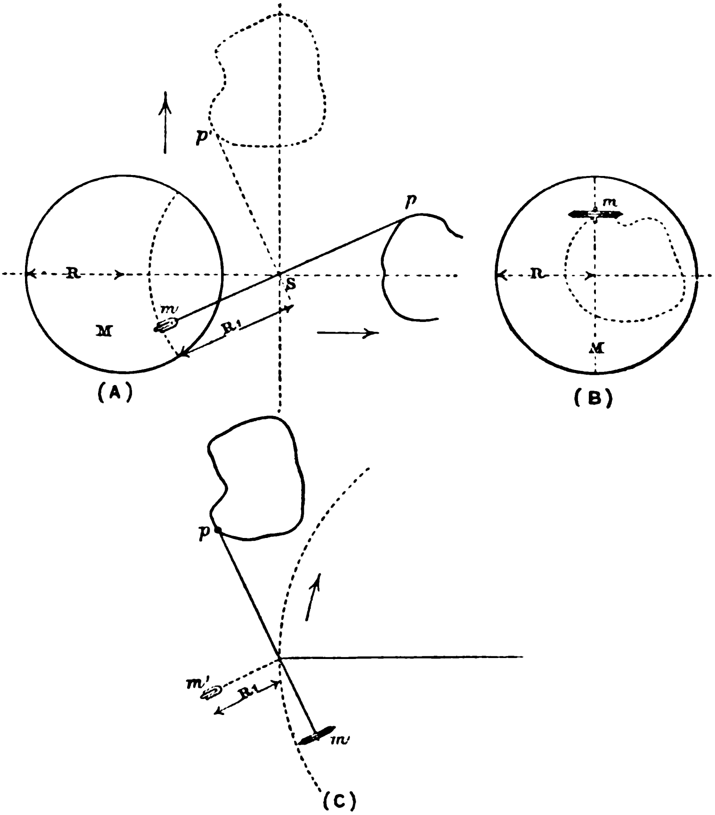
but
$$\frac{S'\,B}{S\,B} = \frac{y}{R} = \sin a,$$

therefore
$$\frac{2\pi r n_1}{\Delta x} = \frac{y}{R},$$

or
$$n_1 = y \Delta x \times \frac{1}{2\pi r R},$$

which is the same result as in the case of both the linear and polar planimeters. In practice, the portion of the pole-arm which carries the pointer is usually perpendicular to the other portion, as shown by the dotted lines, Fig. 12. In this case, the direction of motion of the disk and frame carrying the centre of the pole-arm S must be taken parallel to the guide P′ Q′, that is, perpendicular to the former direction. It has already been shown in the case of the Amsler planimeter, that it does not matter in what path the centre S of the pole-arm is carried, so long as the foregoing con-

FIG. 13.

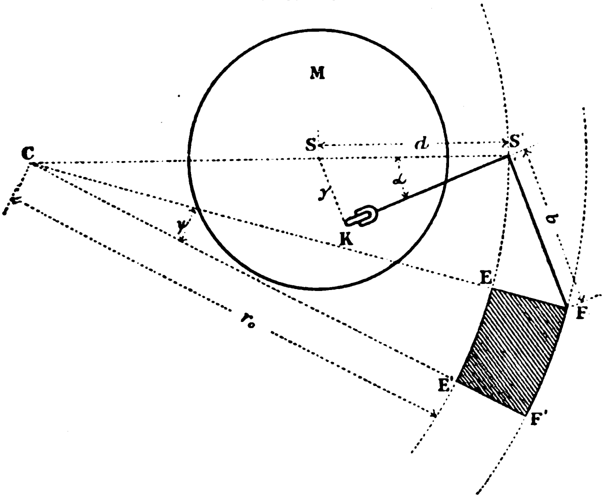


ditions are observed, and thus there are several forms of precision polar planimeters in which the point S is carried in the arc of a circle instead of along a straight line. It may now be made clear, from Fig. 13, that the two first kinds of planimeters are special cases of the last.

(A) Fig. 13. Let R be the radius of the disk, R_1 the radius about which the roller *m* is carried. Then the area of the diagram as already explained can be measured by either pole-arm S*p* or S*p'*.

(B) Fig. 13. Let the radius R_1 of the pole-arm become infinitely great, while R remains finite; thence *m* moves across the disk M in a straight line usually, but not necessarily, through the centre, and the linear planimeter is the result.

Fig. 14.



(C) Fig. 13. Let the radius of the disk become infinitely great, and any motion of such an imaginary disk under these conditions would make the result equivalent to moving the roller over the surface of the paper. Therefore the disk may be removed, and the elementary form of polar planimeter is obtained, the roller being placed in either position as shown at *m* or *m'*, without affecting the result.

The following is a simple explanation of the action of the precision polar planimeter.[1]

---

[1] This proof is a modified form of one given by Czuber. "Technische Blätter," vol. xvi., 1884, p. 58.

Let M (Fig. 14) be the disk, which can be turned by any suitable means through a distance corresponding to the linear travel of its centre about C.

Let r_0 = radius of zero circle (E′ E S′).
r = radius of any circle FF′.
α = ∠ turned through by pole-arm, when the pointer moves from the zero circle to the circle FF′.
ψ = ∠ turned through by radius arm, C S, when an element EE′ F′ F is being described.
a = radius arm = C S′.
b = pole-arm = F S′.
d = S S′.

Then from the figure—

and
$$r_0^2 = a^2 + b^2$$
$$r^2 = a^2 + b^2 - 2\,a\,b\cos(90 + \alpha)$$
$$= a^2 + b^2 + 2\,a\,b\sin\alpha.$$

Therefore
$$r^2 = r_0^2 + 2\,a\,b\sin\alpha,$$

or
$$\sin\alpha = \frac{r^2 - r_0^2}{2\,a\,b}$$

Now the turning of the plate is proportional to ψ, and may, for the arc FF′, be taken as equal to $r_0\,\psi\,c$.

$$y = \text{S K} = \text{S S}' \sin \angle\, \text{S S}'\,\text{K} = d \sin\alpha,$$

where c and d are constant quantities; also if ρ = the radius of the roller,

then
$$\frac{y}{\text{R}} = \frac{\text{linear distance by edge of roller}}{\text{distance travelled by edge of disk}} = \frac{2\,\pi\,\rho\,n_1}{r_0\,\psi\,c};$$

$$\therefore\ y = \frac{2\,\pi\,\text{R}\,\rho\,n_1}{r_0\,\psi\,c}.$$

Therefore
$$\frac{2\,\pi\,\text{R}\,\rho\,n_1}{r_0\,\psi\,c} = d\sin\alpha = \frac{d \times (r^2 - r_0^2)}{2\,a\,b}$$

or
$$n_1 = \frac{r^2 - r_0^2}{2}\,\psi\left(\frac{r_0\,c\,d}{2\,\pi\,\text{R}\,\rho\,a\,b}\right);$$

but $\frac{r_0\,c\,d}{2\,\pi\,\text{R}\,\rho\,a\,b}$ is a constant quantity, and may be made equal to unity.

Therefore $n_1 = \frac{r^2 - r_0^2}{2}\,\psi$ = area of element E E′ F F′.

Thus n_1 is a measure of an element of area, and as the motion of m due to turning of the pole-arm in moving to a larger or smaller circle does not affect the reading when the pointer at F has passed round a closed curve, the final reading of the roller gives the area of any figure.

The actual construction of the precision polar planimeter appears to have been first carried out by Mr. Hohmann, Bauamtmann of Bamberg, in 1882,[1] in conjunction with the well-known mechanician Mr. Coradi, of Zurich. A plan of the first instrument is given in Fig. 16; but it will be more easily understood by reference to the diagram, Fig. 15, which shows a frame (*a*) pivoted at one end (*c*), to a weight G, about which it turns. This frame carries a small disk (*w*), which rolls in contact with the surface of the diagram, and gives motion to the disk M. The roller *m* is moved across the disk in the horizontal direction by a pole-arm centred on S as axis. Referring to Fig. 16, which is lettered in a

Fig. 15.

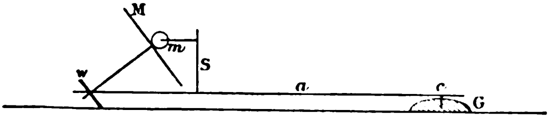
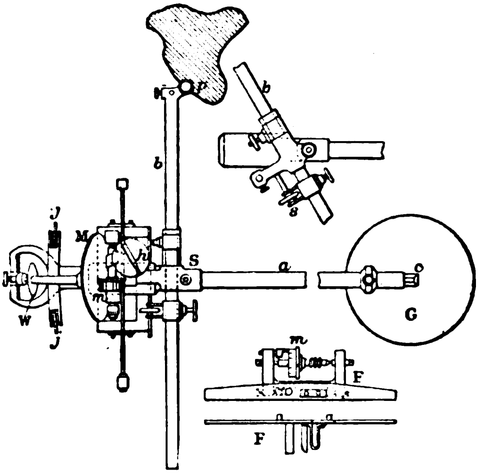


Fig. 16.



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[1] "Hohmann's Präcisions Planimeter, Beschreibung, &c." Dr. W. Tinter. Vienna, 1882.

similar way to Fig. 15, it will be seen how the pole-arm, in turning about the centre S, effects this motion. A plan and elevation of the frame F, which carries the roller *m*, is shown on a larger scale, and this frame is moved backwards or forwards through a slot in the supporting frame. The roller *m* has the arrangement of the screw and worm for obtaining the readings of the dial *h*, as in the Amsler planimeter, and also the vernier in conjunction with the measuring roller. Two rollers *j j′* serve to balance the instrument. The details of the arrangement by which the length of the pole-arm *b* is adjusted are also shown on a larger scale.

In this instrument, the fact that the disk is inclined at an angle makes no difference in the theory of its action, and as the roller W obviously drives the disk so that the angular motion corresponds with the angular motion of the radius bar *a*, the explanation already given makes its mode of operation clear. The case is rather simplified by the fact that the roller *m* is moved radially across the disk.[1]

An instrument of similar kind has been designed and recently described by Professor Amsler-Laffon.[2] This is shown in Figs. 17, 18, and 19, where it will be seen that this disk M which is now horizontal, is turned by means of bevel-wheels z_1 z_2, the back of one of which forms a portion of a frustum of a cone rolling about the centre C of the radius-arm *a a*. The centre is itself a sphere, which allows any side motion of the instrument, due to the inequality of the surface, to take place without affecting the accuracy of the result. The necessary pressure of the roller upon the disk is obtained by allowing the weight of the portion of the frame *b*, which carries the roller *m*, to rest upon the disk by being pivoted by the centres K K (Fig. 18). A peculiar feature of the instrument is that the pole-arm frame can be centred either within or without the frame. If placed in the former position, the reading is twice as great as in the latter, the positions of the centres being purposely adjusted to effect this. The frame can be taken off one centre *s′* (Fig. 17) by unscrewing a set screw at *x*, and at once placed upon the other. The weight *w* can be adjusted in any position by means of the nut and screw *t* (Fig. 17), and so the pressure of the pointer *p* upon the surface of the diagram may be regulated.

In both the above instruments the disks derive their motion from a roller in contact with the surface of the diagram, but in the two next instruments to be described, Messrs. Hohmann and Coradi have caused the disk to be turned in a manner which prevents any such error as from the possible slipping of the above roller. The first instrument of the kind is shown (Figs. 20, 21) in plan and elevation. The disk M is carried by a frame (*a a*) as before, but the frame now swings about a circular stand, the edge of which is toothed, so that the pinion (*i*), which is upon the axis of the disk, is turned, and therefore the disk itself, with the same angular velocity. The weight of the frame and disk is, to a great extent, taken off by means of the light rod (*l*) which swings about a central pillar P. A side view of the pole-arm is shown, and the mode of adjusting it and supporting the portion which carries the roller (*m*), so that by means of centres K K the weight of that portion of the frame is allowed to rest upon the disk.

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[1] A complete analysis of the action of this instrument is given by Dr. W. Tinter, Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereins, vol. xxxiv., p. 90, 1882.

[2] "Planimeter Constructionen," Jan. 1884, p. 22.

FIG. 17.

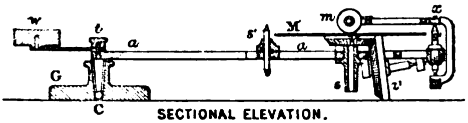


FIG. 18.

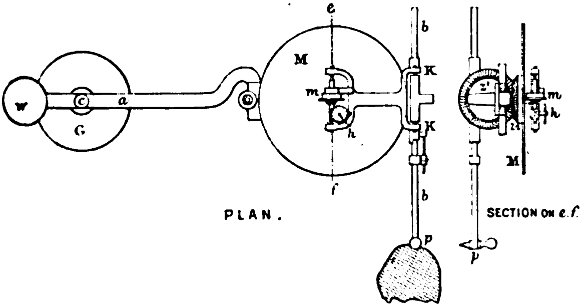
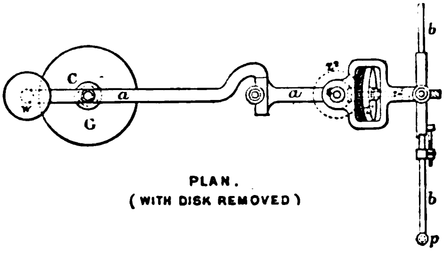
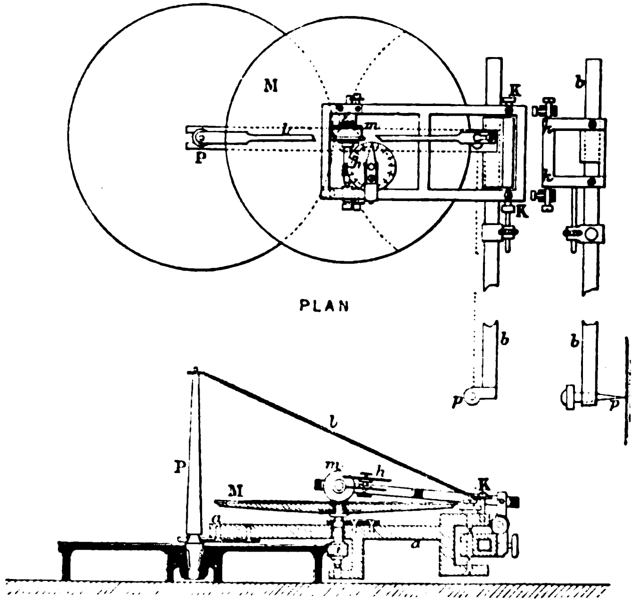


FIG. 19.



It is evident that this instrument works upon identically the same principles as the foregoing ones. This "Freely-swinging" precision-planimeter was followed by another, called the "Plate" planimeter (Fig. 22),[1] which is of still simpler construction. In this form advantage is taken of the fact that the measuring roller need not have its path through the centre of the disk, and a support (*v*) is obtained above the disk, so that its pivot (*q*) can work between centres, the weight of the frame being supported by rollers (*j*). The portion of the pole-arm which carries the roller (*m*) is (as in the last case) pivoted between the centres K K. The dial for higher readings is as in the case of the previous instruments denoted by *h*.

FIGS. 20 and 21.



PLAN

SECTIONAL ELEVATION

The last and most recent modification is the "Rolling planimeter" of Coradi. This approaches nearest to the diagram (Fig. 12), which completely explains its action. Here the centre of the radius-arm is removed to an infinite distance, and the centre of the disk and that of the pole-arm are carried along straight lines parallel to the axis O Y in that figure. The way in which this is effected is seen from Figs. 23 and 24, which show Coradi's rolling planimeter in plan and elevation. Two rollers (c c') are in contact

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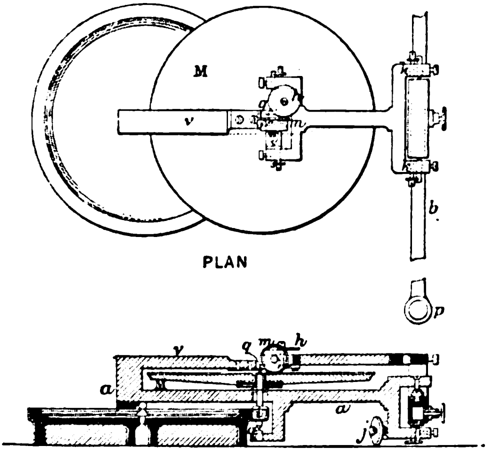
[1] A full account of the theory and action of these are given in "Das freischwebende Präcisions Planimeter und dessen Modificationen." Friedrich Hohmann, Bamberg.

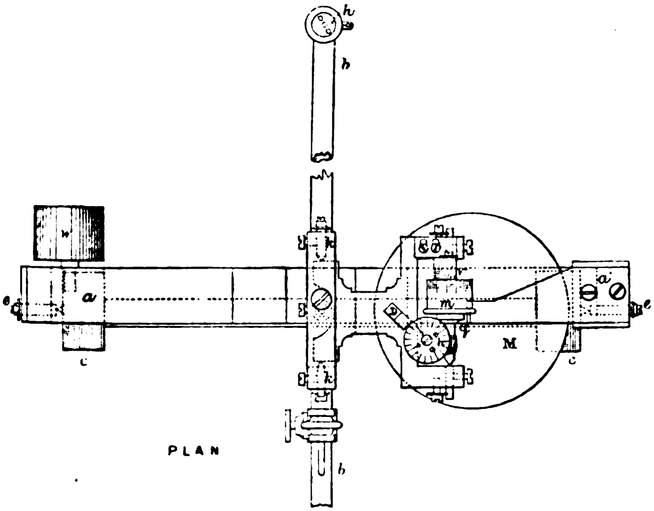
FIG. 22.



PLAN

SECTIONAL ELEVATION

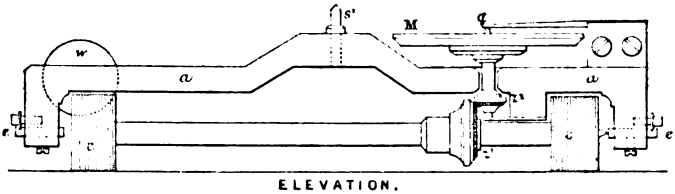
FIG. 23.



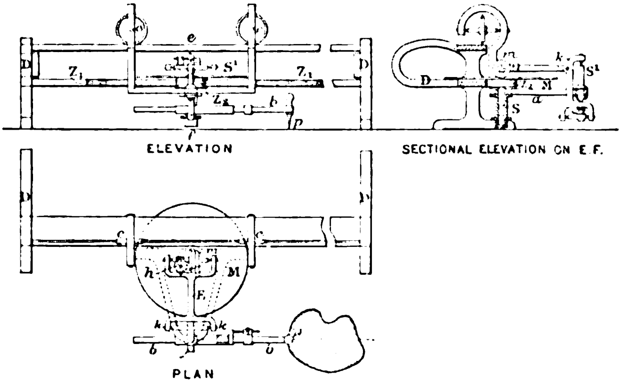
PLAN

with the surface of the diagram, and on their axis is a bevel wheel (z_1) (Fig. 24), which gears with another bevel-wheel (z_2), which is upon the axis of the disk. Thus the wheels z_1 z_2 are turned as the frame is rolled along, and consequently the disk itself. The axis of the rollers *c c* works upon the centres *e e*, which are set screws in the frame (*a a*). The disk M is also carried between centres (*q q*), as in the instrument last described, and also, as in that case, the path of the roller does not pass through the centre of the disk. This instrument, which has many advantages, and, notwithstanding that it rolls on the diagram surface, gives results of great accuracy, has been examined with great care by Professor Lorber, who has given a lengthy description of it and a full account of its theory.[1]

FIG. 24.


S'
M
q
w
a
a
z1
e
c
c
e
z2
ELEVATION.

FIGS. 25, 26, and 27.


e
D
Z1
S'
Z1
D
Z2
b
p
f
ELEVATION
m
k
S1
D
Z1 M
a
S
SECTIONAL ELEVATION ON E.F.
D
D
c
c
h
M
F
k
k
b
b
f
PLAN

The last planimeter of this kind to be examined is one by Professor Amsler.[2] This instrument, shown in Figs. 25, 26, 27, differs from the last in that the tooth-wheel z_2 works in gear with a rack $z_1\,z_1$, which is cut upon a fixed frame D D. Thus, although it is supported by the rollers *c c*, there is no possibility of slipping as far as the turning of the disk is concerned. The rollers run in a groove cut in the frame D D, and the action of the instrument is easy and smooth. The theory of its action is identical with that of the foregoing one, as explained by means of the diagram Fig. 12. The various parts are lettered in the figures to correspond with the explanations of that instrument previously given.

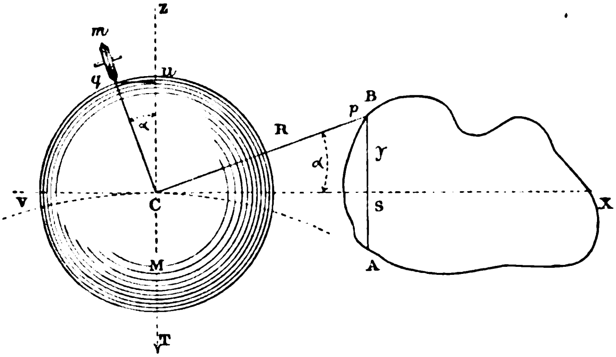
---

[1] "Ueber das Roll planimeter von Coradi, von Franz Lorber." Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereins, vol. xxxvi., p. 135, from whence the figures (23, 24) are taken.

[2] Zeitschrift für Instrumentenkunde, Jan. 1884.

In the instruments hitherto described the surfaces of revolution are limited to the disk and cone, but various other surfaces may be made to replace these. The only one that has been so employed is that of the sphere; and in the present class of instruments, in which slipping takes place, the following property of the sphere is made use of: Let a sphere M (Fig. 28), which replaces the disk (Fig. 2), roll along the axis O X. Then suppose the roller *m* can by suitable means be moved round the surface so that its plane of rotation shall always contain the centre of the sphere and be perpendicular to the arm C B, which corresponds to the pole-arm of the former instruments; it is evident that if the perpendicular be drawn from *q*, the point of contact of *m* with the sphere, to C Z the axis of rotation of the sphere, meeting it in the point *u*, the line *q u* is the radius of the rolling circle of contact of the measuring roller.

FIG. 28.



Therefore
$$\frac{\text{motion of measuring roller}}{\text{motion of sphere along O X}} = \frac{q\,u}{C\,V} = \frac{q\,u}{q\,C} = \sin \alpha.$$

But from the figure
$$\frac{S\,B}{C\,B} = \frac{y}{R} = \sin \alpha.$$

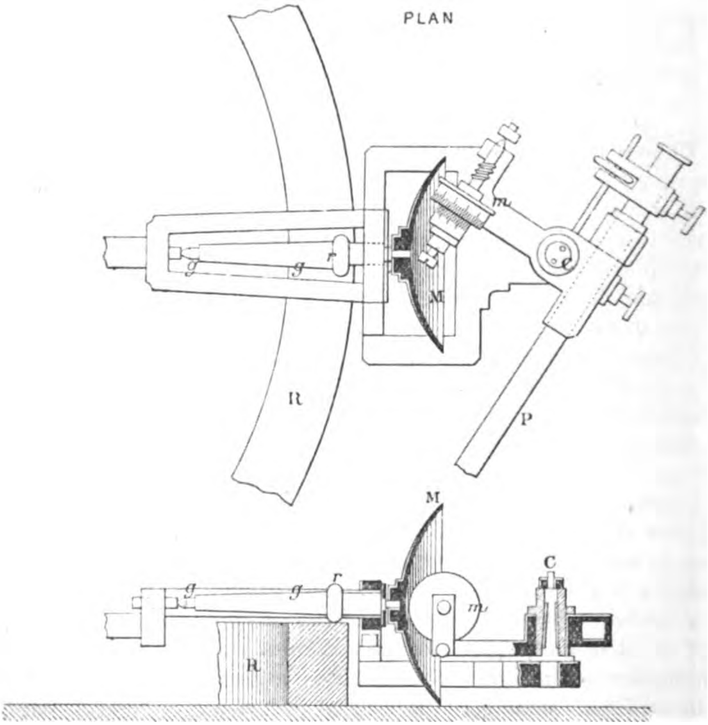
Therefore, adopting the same notation as hitherto used,

$$\frac{\text{motion of } m}{\text{motion of M}} = \frac{2\,\pi\,r\,n_1}{\Delta\,x} = \frac{y}{\text{R}}$$

$$n_1 = y\,\Delta\,x \times \frac{1}{2\,\pi\,r\,\text{R}},$$

which proves that the area of the curve may be measured by any device, on the principle of Fig. 28. It may be shown in the same way as on p. 18, that the result is similar if the sphere rolls upon the arc of a circle, about any centre as T, instead of along the straight line O X. Planimeters of this kind have been constructed by Mr. Hohmann and Professor Amsler. In both cases only portions of the whole surface of a sphere have been employed, and the motion is given by means of an axis, instead of by rolling the

Fig. 29.


PLAN

SECTIONAL ELEVATION

spherical surface upon the diagram. In Mr. Hohmann's planimeter, shown in plan and elevation, Fig. 29, the concave surface M is used. Rotation is given to this by means of an axis $g\,g$, an enlarged portion of which (r) rolls upon a circular metal path R. The pole-arm P turns about a centre c, and so causes the rolling circle of the measuring roller m to vary according to the foregoing principles. This instrument has not come into use. Professor Amsler has employed the convex surface in an instrument somewhat similar to the one described, except that better provision is made for obtaining the required pressure between the surface of the roller and sphere and for giving rotation from the roller-path.[1]

PLANIMETERS IN WHICH ONLY PURE ROLLING MOTION IS ASSUMED TO TAKE PLACE.

There have been many efforts to design instruments in which no slipping shall take place. These efforts have resulted in the production of various instruments which, though they differ in external form and mechanical action, yet rely upon the same mathematical principle of action as the planimeters already dealt with, the particular form of disk and roller or sphere and roller being taken. Thus, in every case there is a measuring-roller or its equivalent, the rate of motion of which has to be varied by some means or other. It is in the method by which this is done that this class of planimeters differs from the other. Instead of obtaining the variation of the measuring-roller in bringing it into contact with circles of different linear velocity by sliding it over the surface of the disk or sphere, one or other of the two following principles are employed. A device equivalent either to (1) bringing in succession a series of measuring rollers into contact with the different imaginary circles; or (2) bringing circles of different linear velocity into contact with a single fixed measuring roller.

The disk-globe and cylinder-integrator of Professor James Thomson belongs to the former class. In this a sphere G (Fig. 30) rolls over the surface of the disk M, but is also in contact with a cylinder $m\,m'$. The motion of G in direction O Y is that in which the roller would slip in the ordinary disk and roller, and does not affect the motion of rotation of $m\,m'$. On the other hand the motion in direction O X, which is due to the turning of the disk, is entirely imparted to $m\,m'$. Thus as G rolls along $m\,m'$, the same effect is in theory produced as if a series of rollers m, m_1, m_2, &c., upon the same axis as the cylinder, were successively applied to the surface of the disk, and all slipping, at any rate from this cause, is avoided. The actual mechanism which has not been employed for a planimeter takes a slightly different external form in the harmonic analyser of Sir W. Thomson's tide-calculating machine.[1]

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[1] **Zeitschrift für Instrumentenkunde, heft i., Jan. 1884, p. 19.**

FIG. 30.

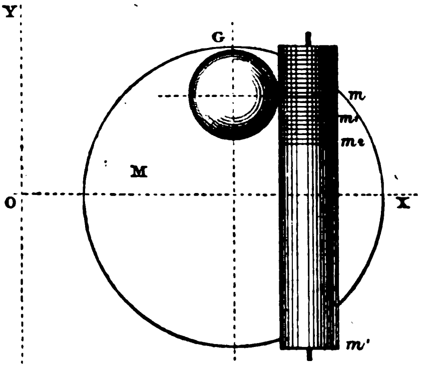
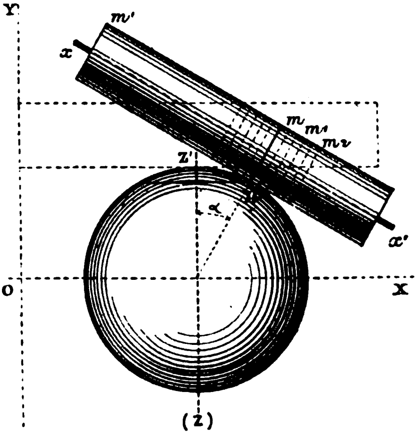


FIG. 31.



The devices which have now to be considered as solutions of the problem under consideration by the first method, are used in connection with the geometrical property of the sphere already discussed, and upon one similar to it.

Let M (Fig. 31) be the plan of a sphere rolling along the line

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[1] Minutes of Proceedings Inst. C.E. vol. lxv. p. 2.

O X, carrying with it, by a frame not shown, a cylinder (m) which can roll about it so as to come into contact at any point q upon its horizontal great circle. Then the rotation of the cylinder may be employed exactly in the same way as the rotation of the roller on the integrator described on page 35, and shown by Fig. 28; but in the present case, instead of causing the roller to slip over the surface, the rolling of the cylinder is practically equivalent to bringing in succession a series of rollers m, m_1, m_2, &c., upon one axis in contact with it.

This principle has been employed both by Professor Mitchelson of Cleveland, U.S., and Professor Amsler. The mechanism of Professor Mitchelson's instrument is shown in Fig. 32. In this a flexible steel band or chain F passing round a semi-circular arc D forces the cylinder C to roll on the sphere G. The cylinder is carried by a frame E, which slides along the bar A by which it is supported. The mode in which it is proposed to apply it to the ordinary Amsler planimeter is shown on a smaller scale Fig. 32A, where b is the pole-arm, a the radius bar, and t the centre of rotation of the latter.

FIG. 32.

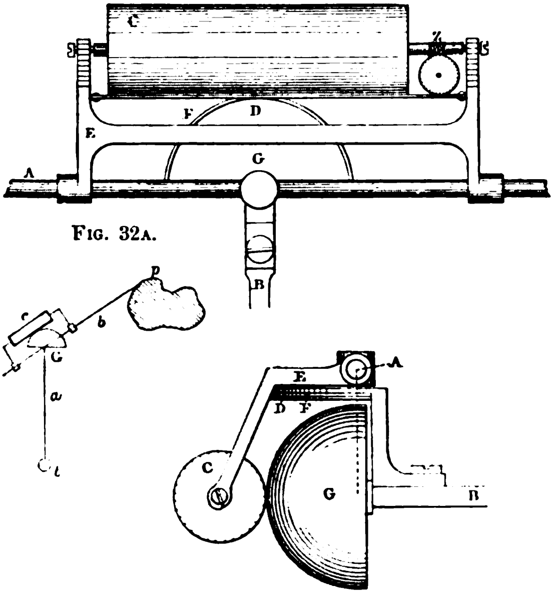
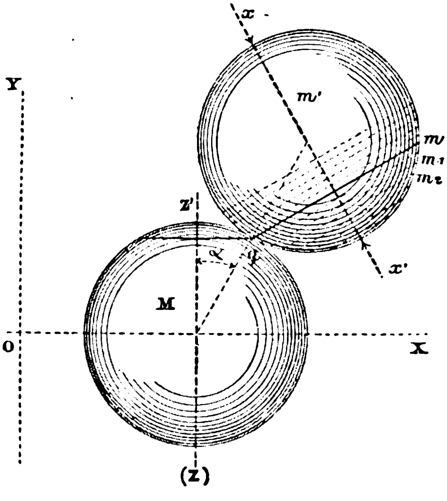


FIG. 32A.

Professor Amsler's planimeter on this principle is similar to the foregoing, except that instead of being carried by two guides as sleeves by a bar, the cylinder-frame is supported on rollers from a frame above, the rolling friction on the latter being less than that of the cylinder on the sphere. Thus the cylinder always moves to its required position. The motion of the spherical surface is obtained from a bevel-wheel upon its axis, which gears with a larger one formed upon the edge of a circular stand or support of the instrument.[1]

A similar principle of the geometry of the sphere has also been employed in an instrument suggested in a Paper in 1855,[2] by the late Professor Clerk Maxwell, when an undergraduate at Cambridge. Instead of the cylinder in Fig. 31, let a sphere m' roll round on the sphere (M), as shown in Fig. 33. Then from the property of the sphere, which is proved at length in the above Paper, the turning of the sphere m' about its axis of rotation x x, relatively to the turning of M along O X, is proportional to the tangent of the angle α in the figure. In the other case it will be remembered that the turning of the cylinder or disk was proportional to the sine of the same angle. By suitable means the principle can be employed in the construction of a planimeter. Two forms of such planimeter are shown in the Paper, and though they

FIG. 33.



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[1] Zeitschrift für Instrumentenkunde, Jan. 1884.

[2] Transactions of the Scottish Society of Arts, 1855.

are both in the form of the linear planimeter, and are scarcely suitable for practical application, yet the matter is dealt with in a way worthy of the inventor. It is evident that this is another case of bringing the equivalent of a series of rollers m, m_1, m_2, into contact with the sphere, though these are no longer of one size, but vary from a diameter zero to a diameter of the size of that of the sphere m.

Coming now to the instruments in which the alternative device adopted for the avoidance of slipping is by bringing into contact with one roller different circles of the disk M, or of its equivalent.

This may be done in the following way. Instead of allowing the cylinder (m) to roll on the sphere M (Fig. 31), and so to change the radius of the imaginary rolling circle (whose diameter is qq') on which it rolls, suppose that the cylinder is kept in contact as shown by the dotted lines, and the axis of rotation zz' of the sphere is turned, as, for instance, would happen if a sphere in combination with rollers were used as suggested for an anemometer by Mr. Ventosa, through an equivalent amount, *i.e.*, through the angle a. This will give the same result as far as the rotation of the cylinder is concerned, but with an important difference. The cylinder (in Fig. 31) or sphere (in Fig. 33) is no longer needed, and may be replaced by the original measuring roller, whose axis has a fixed position parallel to O X. It will be seen that this device practically amounts to bringing different circles on the sphere M into contact with the measuring roller (m), with the great advantage that exactly the same circle on the sphere M is scarcely likely to again roll in contact with the roller (m), though of course the radius may be the same. This method has been recently proposed by the Author, and the mode of carrying it out without involving slipping, by what is called the "sphere and roller mechanism," which mechanism has been explained and developed at length in a Paper before the Royal Society.[1] It need here be only remarked that the planimeter there described, and afterwards exhibited to the British Association at Montreal, was of the linear form, and of little practical use; but the Author has since completed a polar planimeter and exhibited it before the Royal Society.

Only one more area planimeter remains to be mentioned, and this is the one invented and brought before the Physical Society by Mr. C. V. Boys.[2] The principle of action is briefly this :—A wheel, or roller which is not supposed to slip sideways on the diagram, has its plane of rotation kept always at an angle a to the axis O X of the figure to be integrated, such that

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[1] Proceedings of the Royal Society, No. 232, June 1884, now being published *in extenso* in the Phil. Trans.

[2] "Philosophical Magazine." Mr. Boys has since shown the Author a Paper which came into his hands after his own communication in the Philosophical

$$\begin{aligned} y &= \text{ordinate of the curve} \\ &= \tan a \times \mathrm{K} \end{aligned}$$

where K is a constant, and y is the ordinate with respect to O X of that point on the curve which the pointer of the instrument is at the same instant tracing. If the component of a small motion of the wheel parallel to O X is Δx, and the component of the same movement parallel to O Y is Δt

Then
$$\frac{\Delta t}{\Delta x} = \tan a = \frac{y}{\mathrm{K}}$$

$$\Delta t = y \, \Delta x \times \frac{1}{\mathrm{K}},$$

or the distance moved by the wheel parallel to the axis O Y becomes the measure of an element of area. It is easy to see that the height moved by the wheel, becomes a direct measure of the area of the figure. Various examples of the action of this planimeter, called by the inventor the tangent integrator, are given by Mr. Boys; but the action is obviously limited, and an investigation of the theory reveals the fact that it is only a special case of the general problem, not only of the method of applying circles of varying diameter to one roller, but of the sphere and roller mechanism itself. This will be rendered clearer by stating that, in order to employ the component parallel to O Y, the roller was made to work against a cylinder, which, by its turning acted as the measuring roller. Evidently the length of the cylinder limited the travel in that direction. The cylinder was carried bodily along in the direction of its axis (corresponding to O X), and made to effect its own turning, the amount of turning varying with the tangent of inclination of the wheel, and this was sufficient in the application to the steam-engine integrator to be hereafter described, where the longitudinal motion of the cylinder could be made proportional to the stroke.[1] Mr. Boys endeavoured, by various means, to obtain continuous motion in both directions—one being equivalent to bending the

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Magazine was made. This Paper, "Integrator Napisal Bruno Abakanowicz," published at Warsaw in 1864, evidently from the diagrams sets forth the main principles of Mr. Boys' integrator, though the instrument is of rather different form.

[1] "Philosophical Magazine."

ends of the cylinder round, and so attempting to solve the difficulty by what he has termed a "mechanical smoke ring." The Author, however, by approaching the matter from a different point of view, designed the sphere and roller integrator, which is nothing more or less than the inversion of the mechanism of Mr. Boys. In this the roller of Mr. Boys is replaced by the sphere; and instead of the two motions, one of the cylinder about its axis, and one of the cylinder longitudinally, the two rollers are used. It may be easily shown that the turning of the plane of rotation of the roller of the tangent integrator is equivalent to changing the axis of the sphere in the sphere and roller integrator.

MOMENT PLANIMETERS.

The moment of an area, and its moment of inertia about a given line, may be obtained mechanically upon similar principles to those by which a simple area was obtained. If A B C D E, Fig. 1, be the figure whose moment of area and moment of inertia are required about any line OX; then, taking any element of area AB, if y = height of upper portion S B, then the moment of area of the element S B about O X

is

$$m = \text{area of S B} \times \frac{y_1}{2}$$

$$= \tfrac{1}{2}\, y_1^2 \,\Delta x.$$

Similarly the moment of inertia of the element is

$$i = \tfrac{1}{3}\, y_1^3 \,\Delta x.$$

The sum of an infinite number of such expressions as these, when Δx become infinitely small, gives respectively the moment of area and the moment of inertia of the whole figure according to the expressions.

$$\text{Moment of area} = \text{M} = \tfrac{1}{2}\int y^2\, d\, x,$$

$$\text{Moment of inertia} = \text{I} = \tfrac{1}{3}\int y^3\, d\, x.$$

Now there are two possible ways of obtaining these results mechanically. One of these ways is by applying for the purpose the suggestion made by Sir William Thomson in connection with the disk-globe-and-cylinder integrator of Professor James Thomson[1] of using a train of such mechanisms to obtain the integration of a simple linear differential equation. By certain simple arrangements

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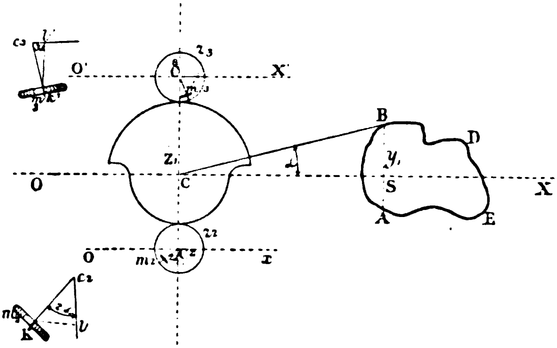
[1] Proceedings of the Royal Society, vol. xxiv., p. 262, and vol. xxvii., p. 371.

The first mechanism would give $\int y\,d\,x$,
" second " " " $\int y^2\,d\,x$,
" third " " " $\int y^3\,d\,x$.

This method need not be further considered here, since, so far as the Author is aware, it has never been carried into actual practice. It may be, however, said that the mechanical difficulties in the way of causing the measuring wheel or roller of the first mechanism to actuate the second, and the roller of the second to actuate the third without introducing serious error, are not easy to overcome, and require a very easily working piece of apparatus. The Author has discussed the applications of the sphere and integrator for the purpose in a Paper to the Royal Society.[1]

FIG. 34.



The other principle is to cause the measuring roller to be directly turned at a rate which is made to vary, not as in the simple planimeter with the value of the ordinate (y), but with its second or third power. Though no method of directly doing this has apparently yet been suggested, yet the same result is practically effected by the beautiful application of a mathematical principle in the "moment integrator" of Professor Amsler.

Let the pole-arm C B (Fig. 34) be attached to a toothed segment (z_1) one portion of which gears with a toothed wheel z_2; the radius being as 2 to 1. Let the centre C of z be carried along O X, while the centre C_2 of z_2 is carried along a line ox parallel to OX. Let

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[1] Proceedings of the Royal Society, No. 232, 1884. The figures and diagrams will shortly be published in the Philosophical Transactions of the Royal Society.

m_2 be a roller acting in every way as the measuring roller of the Amsler planimeter, whose axis is carried in the plane of the wheel z_2, its direction passing through the centre C_2. When the pole arm coincides with O X, let the plane of rotation of the roller m_2 be parallel to O X, and its axis parallel to O Y. When the pole arm is turned through an angle S C B $= a$, the angular motion of the wheel z_2 is twice that of the arm; thus the roller m_2 takes the position shown in the figure.

This is so because
$$\frac{\angle^r \text{ motion of } z_2}{\angle^r \text{ motion of } z_1} = \frac{\text{radius } z_1}{\text{radius } z_2} = \frac{2}{1},$$
$$\therefore \angle \mathrm{K}\, c_2\, l = 2\, a.$$

Suppose the pointer p to move through the width of the element SB at a height $= y$, and with it z, and z_2, the roller m_2 being in contact with the diagram surface. Then, by what was proved in the case of the Amsler planimeter, and adopting the same notation.

$$\frac{\text{Turning of } m_2}{\text{Motion of translation of } m_2} = \frac{2\,\pi\, r\, n_2}{\Delta\, x} = \frac{l\, c_2}{c_2\, \mathrm{K}}$$
$$= \cos 2\, a$$
$$= 1 - 2 \sin^2 a,$$

but
$$\frac{\mathrm{S\,B}}{\mathrm{C\,B}} = \frac{y_1}{\mathrm{R}_1} = \sin a \text{ (where C B} = \mathrm{R}_1),$$

$$\therefore \frac{2\,\pi\, r\, n_2}{\Delta\, x} = 1 - 2 \sin^2 a = 1 - \frac{2}{\mathrm{R}_1{}^2}\, y_1{}^2,$$

or
$$n_2 = \left(\frac{1}{2\,\pi\, r}\right) \Delta\, x - \left(\frac{2}{2\,\pi\;\, r\, \mathrm{R}_1{}^2}\right) y^2\, \Delta\, x.$$

When the complete travel of the curve has been made, the sum of a series of quantities similar to the first becomes zero; so that, by making the constant $\left(\frac{1}{\pi\, r\, \mathrm{R}_1{}^2}\right)$ equal $\frac{1}{2}$, the reading of the roller gives the value—

$$\mathrm{M} = \tfrac{1}{2} \int y^2 d\, x,$$

or the moment of area of the figure B D E A.

For the moment of inertia the segment of z_1 is used, the radius of which is three times that of another wheel, z_3, with which it gears. The action of a roller m_3, carried by the wheel z_3, is exactly the same as that of m_2, except that its angular motion is three times as great as the pole arm C B, instead of twice as great, as in the case of the other roller.

By reasoning similar to that already adopted, and taking the plane of rotation of m_3 perpendicular to O X in its initial position, instead of, as in the former case, parallel to it

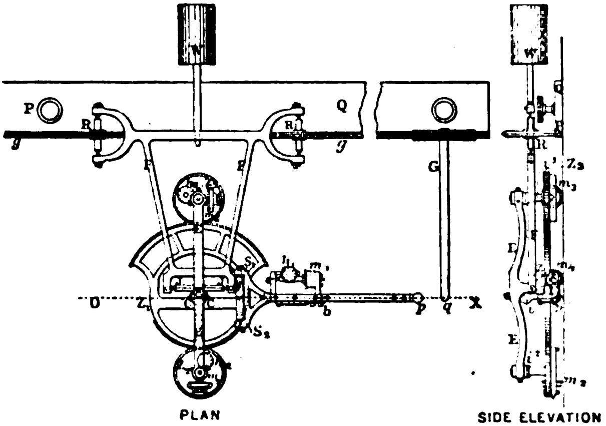
$$\frac{\text{travel of } m_3}{\text{motion of translation of } m_3} = \frac{2\,\pi\,r\,n_3}{\Delta\,x} = \frac{l'\,c_3}{c_3\,k^1}$$
$$= \sin 3\,a$$
$$= 3\sin a - 4\sin^3 a.$$

$$\frac{\text{S B}}{\text{C B}} = \frac{y_1}{\text{R}} = \sin a.$$

Therefore $$\frac{2\,\pi\,r\,n_3}{\Delta\,x} = 3\sin a - 4\sin^3 a = 3\,\frac{y_1}{\text{R}_1} - 4\,\frac{y_1^{\,3}}{\text{R}_1^{\,3}}.$$

Or $$n_3 = \left(\frac{3}{2\,\pi\,r\,\text{R}_1}\right) y_1\,\Delta\,x - \left(\frac{4}{2\,\pi\,r\,\text{R}_1^{\,3}}\right) y_1^{\,3}\,\Delta\,x,$$

Figs. 35 and 36.



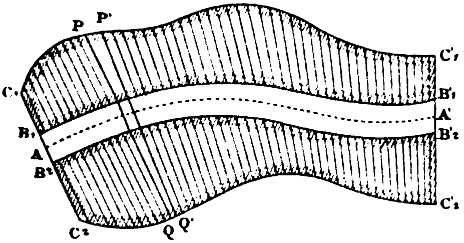
which, when the pointer is taken round the curve, gives, with suitable values of the constants,

$$n_3 = \int y\,d\,x - \tfrac{1}{3}\int y^3\,d\,x$$
$$= \text{area of B D E A} - \text{moment of inertia of B D E A}$$
$$= \quad \text{A} \quad - \text{I}.$$
or $$\text{I} = \quad \text{A} \quad - n_3.$$

The instrument, Figs. 35 and 36, has an area planimeter attached to it, so that by reading the rollers m_1 and m_3, and subtracting the results, the moment of inertia is obtained.

The details of the moment planimeter shown (Figs. 35 and 36) are easily explained. A guide P Q of steel has a groove g g, which is placed parallel to the axis O X by means of the gauges G, one, as shown, being at each end, which are adjusted with their points q upon the line O X. The rollers R R run in the grooves g g, and support a frame F F, which carries by means of an axle J J, the frame E E. This frame supports the toothed segment z_1, and the two toothed wheels, z_2, z_3, upon vertical axes. The former between centres, one of which is shown, Fig. 36, i, the latter by steel axles within the column $i_2\, i_3$. The pole-arm carries, in addition to the pointer p at the end, the roller m_1 with its dial h_1, forming an ordinary planimeter, and is itself carried on the centres s_1 s_2. The two other rollers and dials are shown as m_2 m_3 and h_2 h_3 respectively. The weight W serves to balance the instrument, so as to avoid undue pressure on the paper, and the motion is so smooth as to enable a curve to be traced with the greatest ease and accuracy.

FIG. 37.



Attention has been called by the late Dr. Merrifield and others to the valuable applications of this instrument for purposes of naval architecture, but so far as the Author is aware, no account has been given in this country of its applications in civil engineering, as proposed by Professor Amsler.[1] The following brief account of the methods in the case of calculating the contents of embankments, cuttings, &c., is therefore given from an abstract for which the Author is indebted to the kindness of Dr. A. Amsler:—

Let Fig. 37 be the plan of a portion of an embankment or cutting, the character of which is supposed to be the same throughout, viz., of uniform width of roadway, and uniform side-slopes, the surface of the ground, the gradient, and the horizontal curvature of the roadway, being restricted in no way. A A' represents the centre line of the railway; B_1B_1' and B_2B_2' its two borders; $C_1\,C_1'$ and $C_2\,C_2'$ the intersections of the side-slopes with the surface of the ground. Suppose now the embankment or cutting to be divided into thin layers by vertical planes, perpendicular to the centre line A A′ of the roadway; P Q and $P_1\,Q_1$ may be the intersections of two adjacent planes with the plane of the diagram.

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[1] "Anwendung des Integrators zur Berechnung des Auf- und Abtrages bei Anlage von Eisenbahnen Strassen und Kanälen." Von I. Amsler-Laffon.

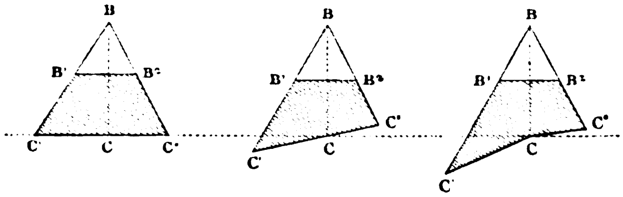
Then if p = area of section P Q,
Δs = interval between P Q and $P_1\,Q_1$ measured upon the centre of gravity of the section.

Total volume of embankment is (from one of the properties of Guldinus)—

$$V = \int p\,d\,s,$$

the integral extending over the whole length of the embankment under consideration.

Fig. 38.



There are three cases dealt with in the Paper of Professor Amsler, corresponding to the three forms of sections, I, II, or III, Fig. 38.

The first of these, I, is simple enough, since the centre of gravity of the section always coincides in plan with the centre line of the roadway, and the plan of operation is as follows:—

Let Fig. 39 represent a longitudinal section of a portion of the embankment of uniform gradient, developed into a plane; the straight line E′ E E″ represents the top of the embankment; G′ G G″ the profile of the ground; the straight line A′ A A″, which is parallel to E′ E E″, is the locus of the imaginary vertex of the trapezoidal cross-sections. The level line M N is the line to which the offsets of the profile of the surface of the ground refer. B G shows the intersection of a vertical cross-section with the figure, and A G the intersection of a plane perpendicular to the top of the embankment (and also to the line A′ A A″) with the figure.

Let $i = \angle \mathrm{A\,G\,B} = \angle \mathrm{M\,N\,A}$ = gradient;
$y = \mathrm{A\,G}$ = distance of vertex to bottom of embankment;
$y_0 = \mathrm{A\,E}$ = distance of vertex to top of embankment;
$2\,\beta$ = angle at vertex at A.

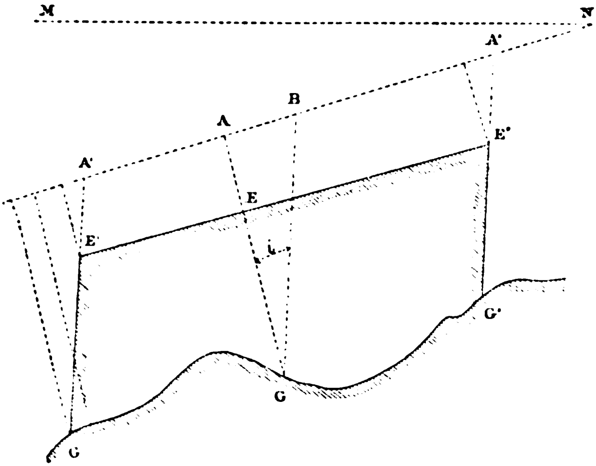
It may be easily proved the area of the section made by the plane A E G is—

$$p = (\mathrm{A\,G}^2 - \mathrm{A\,E}^2) \tan \beta = (y^2 - y_0{}^2) \tan \beta$$

but since $\mathrm{V} = \int p\, d\, x$

Therefore volume $= \tan \beta \int (y^2 - y_0{}^2)\, d\, x.$

FIG. 39.



And thus, if β is known, the volume of the portion E′E″ G″G′ (Fig. 39) is easily found with the mechanical integrator thus—

Take A′ A A″ as the axis of moments, and adjust the rail of the instrument so as to be parallel to it. Start the pointer anywhere on the shaded figure, and trace round it; the travel of the roller m_2 being denoted by M, the scale of the drawing longitudinally being—

$1'' = m$ feet,
and vertically $1'' = n$ feet;
then volume $= \mathrm{V} = 20\, m\, n^2 \tan \beta \times \mathrm{M}$ cubic feet.

It only remains to insert a known value for tan β, which is easily done thus—

Let Fig. 40 be a perspective view of the sections A E G and B G (Fig. 39), where—

$$\angle\, C_1 B C_2 = 2\,\alpha.$$

Then from the diagram $\dfrac{C_1 G}{A G} = \tan\beta$;

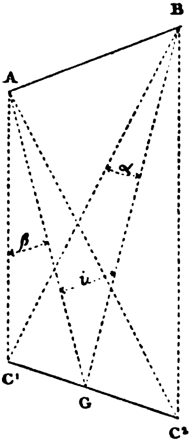
also $\dfrac{C_1 G}{B G} = \tan\alpha$ and $\dfrac{A G}{B G} = \cos i$.

Therefore
$$\tan\beta = \frac{\tan\alpha}{\cos i},$$

or
$$V = \left(20\, m\, n^2 \frac{\tan\alpha}{\cos i}\right) M,$$

where $\angle\,\alpha$ and $\angle\, i$ are known constants.

Fig. 40.



To complete the calculations for the whole route separate portions are taken, with the various proposed gradients.

The above formula is exact for the integrator shown in Fig. 36, as arranged for English measures, a complete revolution of the measuring roller being taken as a unit of reading.

It is to be noted that nothing is supposed as to the curvature of the centre line of the roadway horizontally, as it is supposed to be developed in the figure. Also, that the aggregate error arising from the assumptions that the cross-sections are exact trapezoids will in most cases be very slight, on account of the errors in cuttings and those in embankments partly compensating for each other, in addition to the cutting and filling in each section, as shown in Fig. 41, where the small triangular portion in dotted lines C′ DH represents the amount taken off the former, and added to the latter.

Alterations of the proposed roadway, otherwise involving tedious calculations, simply necessitate an alteration in the line A′ A A″, and a repetition of the mechanical work of the integrator, but need no fresh diagram. In preparing the drawing, allowance should be made for ditches along the roadway in cuttings, which is easily done, as shown in Fig. 42, where $B_1 B_2$, which equalizes the amounts taken and left, must be considered as the roadway line. In the case shown in Fig. 43, the excess of the embanking over the cutting is approximately equal to the layer above the dotted line C_1C_2. The contents of this layer could be measured either by considering it as an embankment, and treating it as such, or by the simpler—and for a first estimate sufficiently accurate method—of assuming its section to be a parallelogram. The area of the shaded portion (Fig. 43) is then simply to be measured, and the result, multiplied by the length of the road, gives the required contents. The supposition that the slopes C D and C′ D′ are the same is also sufficiently accurate.

Fig. 41.

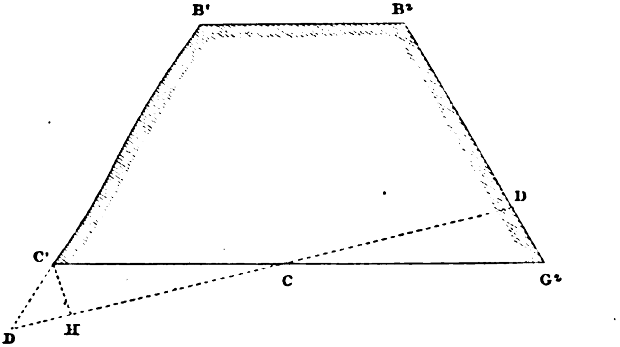
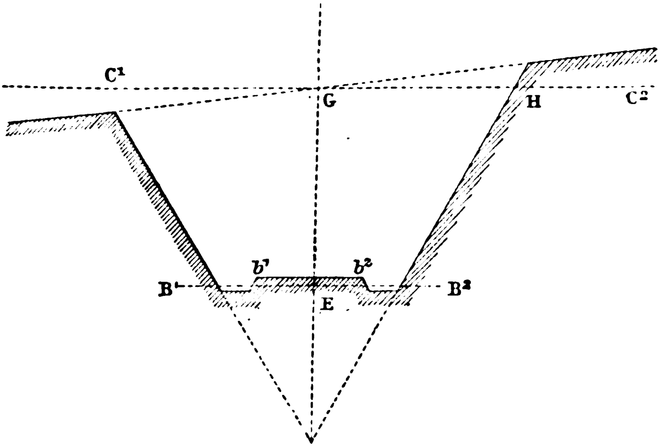


Fig. 42.



The foregoing is the first method described by Professor Amsler, and is extremely simple, but obviously only approximately accurate. The two other methods are capable of giving very accurate results, and are dealt with by him at considerable length. Only a short account of them will be given here.

Fig. 43.

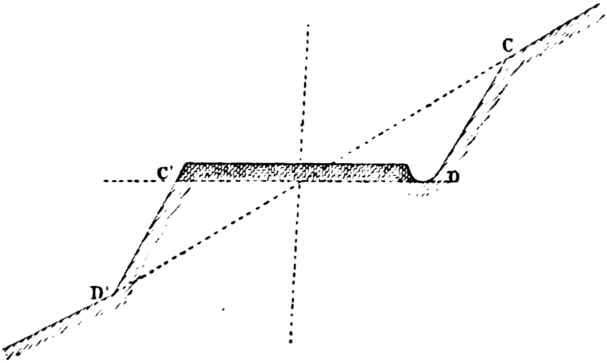
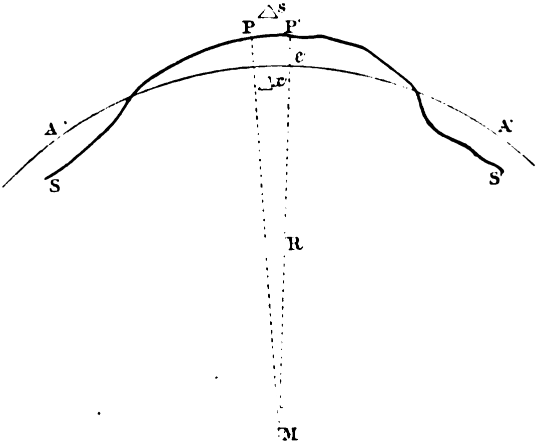


Fig. 44.



The first thing to be noted is that, as a rule, the centre of gravity of the section will not really coincide in plan with the centre line of the roadway, but will curve at the line S P P′ S′, Fig. 44, A A′ being the true centre line. Thus, in the expression $\int p\, d\, s$, the value of $d\, s$ does not coincide with $d\, x$, as hitherto assumed. From the figure it is seen that—

$$\frac{\Delta\, s}{\Delta\, x} = \frac{\text{R} + e}{\text{R}},$$

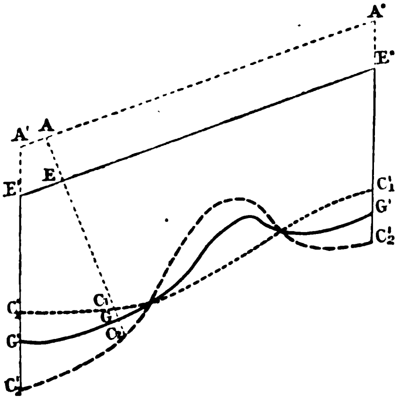
where R is the radius of curvature of the centre line.

Therefore $$\Delta\, s = \Delta\, x \left(1 + \frac{e}{\text{R}}\right),$$

or $$\text{V} = \int p\, d\, s = \int p\, d\, x + \int \frac{p\, e\, d\, x}{\text{R}},$$

and this expression must be used.

Fig. 45.



The first of the two methods assumes the base of section to be inclined, but not broken (Fig. 38, II.), and the side-slopes, gradient, and radius of a given portion to be constant. A diagram is prepared, as shown in Fig. 45, in which the dotted lines now represent intersection of the sides of embankment with the surface of the ground, which do not, as before, coincide with the contour of the centre line.

From this figure
$$y_0 = \text{A E}$$
$$y_1 = \text{A C}_1$$
$$y_2 = \text{A C}_2$$
$$2\,\beta = \angle \text{ at vertex A.}$$

Then by similar reasoning to that previously employed it may be proved that—

Area of element section $= p = (y_1\, y_2 - y_0{}^2) \tan \beta$

and $$e\, p = y_1\, y_2\, (y_1 - y_2)\, \frac{\tan^2 \beta}{3}.$$

$$\therefore\ V = \tan\beta \int (y_1\, y_2 - y_0^2)\, d\,x + \frac{\tan^2\beta}{6\,r} \int y_1\, y_2\, (y_1 - y_2)\, d\,x.$$

By a simple transformation this expression is brought into such a form as to allow of mechanical integration. The final formula being—

$$V = \frac{\tan\beta}{2}\, U + \frac{\tan^2\beta}{6\,r}\, W,$$

where

$$U = \tfrac{1}{2}\int (y_1^2 - y_0^2)\, d\,x + \tfrac{1}{2}\int (y_2^2 - y_0^2)\, d\,x - \tfrac{1}{2}\int (y_1 - y_2)^2\, d\,x$$

$$V = \tfrac{1}{2}\int (y^3 - y_0^3)\, d\,x - \tfrac{1}{3}\int (y_2^3 - y_0^3)\, d\,x - \tfrac{1}{3}\int (y_1 - y_2)^3\, d\,x.$$

Another simple diagram has to be prepared, and by means of three operations of the integrator, the values of U and V are given thus—

$$U = 20 \times m\,n^2\,(v_1 + v_2 - v_3)$$

$$W = m\,n^3\,\{320\,(u_1 - u_2 - u_3) - 100\,(w_1 - w_2 - w_3)\}$$

where m and n have the significations formerly explained, and u, v, and w are the respective readings of the area, moment of area, and moment of inertia rollers in each of the three operations. Considering the great amount of calculation thus saved, and the accurate nature of the results, this second method, although involving rather more labour than the first, is a very important one.

The third method, which deals with the broken base, is much the same in principle as the second, but the expressions become more complicated, whilst six readings of the measuring rollers are involved. The case of an embankment, consisting partly of a cutting, is completely and accurately worked out by this method.

The Paper of Professor Amsler concludes with an example of the application of his integrator to the problem of the strength of a girder.

CONTINUOUS INTEGRATORS.

Any piece of mechanism which continuously adds up results may be regarded as a continuous integrator. Of such instruments, revolution counters as employed in meters of various kinds, form the simplest example, and correspond in action to the devices already described, by which the linear measurement of a boundary is performed. These will not be further referred to, and it is only necessary to consider those computing mechanisms which, dealing with the result of two simple unit measurements, correspond in principle to area planimeters.

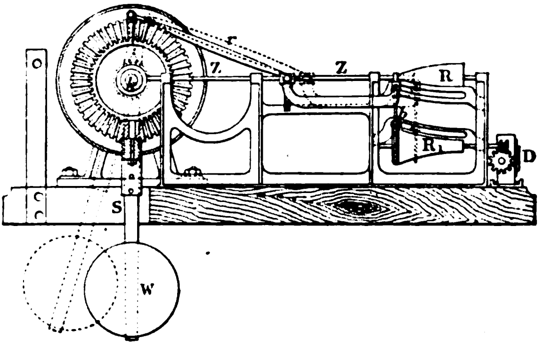
It appears that Poncelet before the year 1838 suggested the employment of a continuous integrator for computing the two factors in dynamometrical measurements. This was described by Morin in 1838 as applied in his "compteur" for registering the work done by a team of horses, dragging a loaded carriage at any given velocity over any length of road. The principle employed was that of the disk and roller, the use of which as already shown had been suggested for application in a planimeter more than twenty years before. In the case in question, the disk was turned by an endless cord or band from one of the wheels of the carriage, while the position of the roller on the disk was caused to vary with the tractive force, and its reading thus gave the product of force and space, or the actual work done.

In 1840 a Committee of the British Association, consisting of Professor Moseley, Mr. Enys, and Mr. Hodgkinson, was appointed to procure the dynamometrical apparatus of Mr. Poncelet, and to obtain a series of experiments on the duty of steam-engines by means of that apparatus, the sum of £100 being placed at their disposal for the purpose. The report of this committee in 1841 describes at length the "constant indicator" of Professor Moseley, which was in reality a continuous steam-engine integrator. It was entirely a new instrument, except that the principle of the disk and roller was employed, and also the traction springs of General Morin. The pressure of steam was allowed to act upon a piston so as to vary the position of the measuring roller, while motion was given to the surface of revolution by means of the stroke of the engine. The surface of revolution was a cone, which was substituted for a disk, as by this arrangement the rapidity of the changes of velocity due to corresponding changes in the position of the integrating wheel is diminished in the same proportion in which the sine of one-half the angle of the cone is less than unity. The force necessary to drive the integrating wheel is diminished in the same proportion, and therefore the chance of an error arising from the slipping of the edge of the integrating wheel on the surface which gives it motion. The reports of the committee in 1842, 1843, and 1844 (which was joined in the first of these years by Dr. Pole), show that the action of the above instrument was, as far as could be determined in its application to a single-acting Cornish engine, very satisfactory, but apparently no mention has been made of it, or results obtained from it, in any succeeding report.

Various other steam-engine integrators have been brought forward since then, most of them acting upon the same principles; amongst these is the recent power-meter of Messrs. Ashton and Storey, which is described at considerable length in the American edition of Weisbach's Mechanics as apparently something new. It is, however, the same instrument as Moseley's integrator, except that it employs a spiral instead of a straight spring, and returns to the use of the flat disk.

The disk and roller has also been since the time of Morin applied in many dynamometers, which thus become really "ergometers" or "work" measurers. In a series of articles which recently appeared in "La Lumière Electrique" those of Hirn, Megy, Bourry, and Darwin, are described as having a "totaliser"[1] or integrator of this kind attached to them. The position of the measuring roller varies with the force exerted or transmitted, and the motion of the disk with the revolutions of the motor or machine. Thus by suitable counting apparatus the continuous product is given of force and space, or work done.

FIG. 46.



A cone has sometimes been used instead of the disk with dynamometers, as in that of Baldwin and Eickemeyer, used at the Centennial Exhibition in 1876 for testing mowing-machines, in which, instead of a measuring-roller, a cylinder is placed with its axis parallel to one side of the cone, while an endless band of round cord is rolled along between the two surfaces, so as to transmit the varying motion of circles of different radius on the cone.[2] Fig. 46 shows the apparatus of Mr. Roury applied to a transmission-dynamometer.[1] In this the force is transmitted through a differential train of three bevil wheels, the middle one of which is attached to the spindle (S), which supports the weight (W), and is suspended from the main shaft by the joint at (*k*), about which the whole can turn. Thus the deviation of the weight from the vertical (as shown by the dotted lines) changes with the force. The change of position of the spindle (S) causes a band (*b*) to move along the surfaces of revolution R R_1, the upper one R being turned from the shaft by the spindle (Z Z). It is to be noted that the distance of the band (*b*) from its zero position is not directly proportional to the force represented by the change of position of the weight, and therefore the surfaces must be formed with a certain curve, found by construction, in order that the dial and counting apparatus at D may correctly give the product of the two variables, force and space, and so the work transmitted through the dynamometer.

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[1] An account of these, with several additional ones, will be found in Dredge's "Electric Illumination," vol. ii., section iii., p. 192.

[2] "The Practical Dictionary of Mechanics." E. H. Knight. Vol. iv., p. 287.

It cannot be said that continuous integrators of this kind are at present practically employed to any great extent. There are probably two reasons for this. One is the want of durable and reliable instruments. The other, the question as to how much, and to what degree they are really needed.

With regard to the first of these it is evident that in all the arrangements hitherto considered (with the exception of Baldwin and Eickemeyer device) there is that slipping of surfaces in contact, which, though of little effect as far as wear goes in the limited operations of a planimeter, becomes a very serious consideration when continuous action is required to be maintained. The only integrator of the second, or non-slipping class, which, as far as the Author is aware, has yet been practically applied, is the "power-meter" of Mr. Vernon Boys. This instrument is shown in Figs. 47 and 48, and acts upon the same principle as Mr. Boys' integrator. The piston C, subject to the varying pressure in the engine-cylinders, with which the barrel A is connected by the connections at B and B^1, is moved up and down against or with the tension of the spring D; its rod acting on the arm *g* causes the plane of rotation of the roller G to take positions more or less inclined to the axis of the cylinder H. This cylinder H is moved to and fro with the stroke of the engine by means of the cord L, Fig. 48, and the roller G being in frictional contact with it causes it to turn round to a greater or less extent, according as the plane of G is more or less inclined to the axis of H. The amount of its revolution is registered by the counting apparatus in I (Fig. 48), to which the axis of H is geared, and is thus a measure of the power of the engine, for it gives the product of the tangent of the angle to which G is inclined and the distance moved through by H, that is the product of pressure of steam into the stroke of the engine. The steam being (as originally in Moseley's and also in subsequent integrators) supplied both above and below the small piston, the absolute pressure is given. Thus, in the present case, as the change of pressure on C at the beginning and end of each stroke causes the rod of g to be alternately above or below the axis of H, so the motion of the cylinder to and fro will always cause the cylinder H to turn in one direction, and thus to continuously integrate the work done. This device only enables a reciprocating movement of the cylinder H to be made, and the Author has already mentioned the device of the sphere and rollers, which by the inversion of the higher pair of Mr. Boys, enables

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[1] "Registering Apparatus." M. Roury. Civil Ingénieur, vol. viii., 1862, p. 367.

FIG. 47.

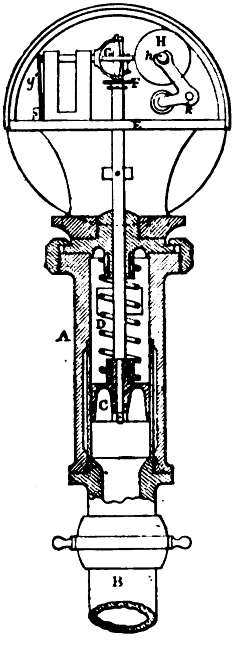
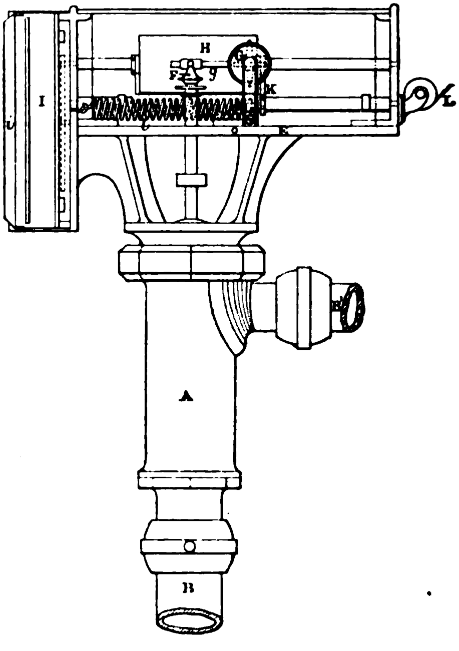


FIG. 48.



continuous motion to be obtained; and is suitable for application in dynamometers, electric-motors, and other purposes.

With regard to the want of such instruments a very strong case was made out by the committee, already mentioned, in their report in 1841, where the application of a continuous integrator to steam-engines was alone discussed. The application has been made to electric-motors, and in trials of motors and machines generally, and there is little doubt if continuous integrators combining the three qualities of durability, accuracy and cheapness could be produced, that in these days of increased regard for measurement of all kinds, there would be a much larger and increasing application of them.

LIMITS OF ACCURACY OF INTEGRATORS.

In all calculating machines accuracy of the result must be the question of first importance. Assuming the theory relied on in the various instruments for the mathematical operation to be correct, the accuracy depends primarily upon the mechanical arrangements, though in the case of planimeters it also depends upon the skill and care of the manipulator, and involves the question of a personal error. This latter point need not be considered, partly because this occurs more or less in all results obtained by observers, but also because it is less than might be at first anticipated, from the fact that in tracing the pointer round the curve there is no reason why the error due to moving it on one side should exceed that due to moving it on the other side, that is why equal errors of opposite effect upon the final reading should not be made.

It has been seen that the action of all integrators, except mere revolution-counters, depends upon the motion of the measuring roller, or its equivalent, over surfaces of various forms, therefore the above-mentioned mechanical arrangements resolve themselves into an examination of the nature of the frictional contact of two surfaces. It was for this reason that integrators have been classified according to the nature of this frictional contact, and it now remains to investigate the nature of this, to show to what the classification leads, to give the direct results of experiments upon the subject, and also the indirect results obtained from the instruments themselves.

Planimeters and integrators generally have been divided into—

I. Those in which the frictional surfaces slip as well as roll over each other.

II. Those in which slipping of the surfaces is supposed not to take place.

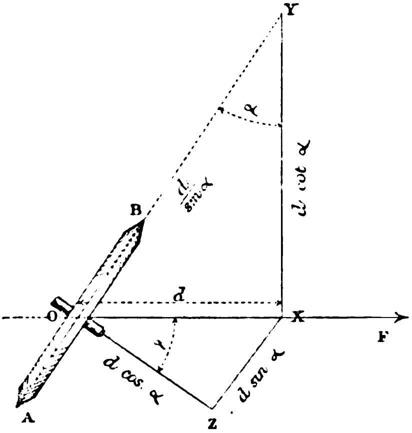
The order of this arrangement was adopted upon historical grounds, and also because the former class is at present by far the most important; but it would be more convenient, upon mere grounds of mechanical simplicity, to invert the order.

Let A B (Fig. 49) be the plan of the measuring-roller. Suppose a force applied in the direction O X, making an angle (a) with the plan of the axis of A B.

Let $d = \text{O X}$ = distance through which the force acts.

1st. Suppose that frame which carries the measuring-roller is free to move in any direction horizontally, but maintains the plane of rotation of the roller vertical, then the application of a force along O X, at the centre of A B, will cause it to roll along the line coinciding in direction with the plan of the centre line AB of the roller, that is along the line O Y. This will always be the case except when this force is applied in the limiting case in the direction perpendicular to the plane of A B (*i.e.* when a = O).

Fig. 49.



Thus the distance in this case travelled by the centre of A B, which is the same as the path rolled by it, is

$$\text{O Y} = \frac{d}{\sin a},$$

and the distance moved through by the centre at right angles to O X is

$$\text{X Y} = d \cot a.$$

The latter value is the one usually taken or recorded by the instruments at present in use, but depends directly upon the former.

Next, suppose the frame carrying the roller is constrained either by guides, as in the linear planimeter, or by the radius-bar of the polar planimeter, or otherwise, to move in the direction of O X, that is, in the direction in which the force acts. When the centre of the roller has reached the point X, that is, when the force has been exerted through a distance O X,

Then $\quad$ O Z = distance slipped by A B = $d \cos a$,
$\qquad\quad$ X Z = distance rolled by O B = $d \sin a$.

Upon the degree of accuracy with which the above conditions are fulfilled depends the correctness of the working of all integrators; for not only do these two cases entirely cover the action of the two classes of planimeters and the corresponding continuous integrators, but one of the limiting cases in each, viz., that in which the force acts in the plane of rotation of the wheel (when $a = 90°$), represents the conditions under which the wheel of the boundary measurer or opisometer is employed. It may be therefore said that the theory of mechanical action of integrators is based upon one or other of the following assumptions, in which the limiting case, (namely, when $a = 90$), is included.

Class I.—That the rolling of the planimeter when slipping is allowed is

$$N_1 = k_1 d \sin a.$$

Class II.—That no slipping takes place, which amounts to the assertion that

$$N_2 = k_2 \frac{d}{\sin a},$$

N_1 and N_2 being the readings in each case, and k_1 and k_2 suitable constants for the instruments.

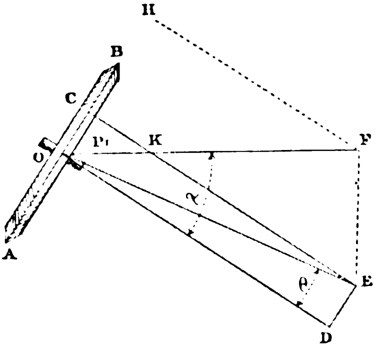
It is easy to see that the first of these is really the assumption made for all instruments in Class I.; but in the various instruments in Class II., it is only with the planimeter of Mr. Boys that it becomes directly obvious that the above assumption is made. With the others though it is less evident, nevertheless, it will be found, on examination, to be equally true that the second supposition is really made, and that upon its truth the correct action of all instruments in the second class depends. The forces acting in each of the two cases must therefore be taken into consideration and the mechanics of the problem examined.

Proceeding in order of simplicity, Class II. will be examined first.

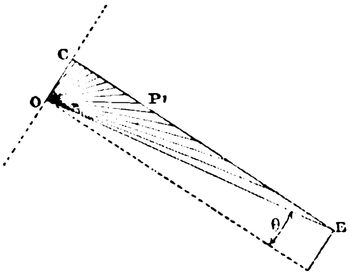
Let A B in both cases (Fig. 50) be the plan of the measuring-roller.

Let S = re-action of surface upon which A B rolls, that is, the force with which it is kept in contact with it;
μ = coefficient of friction between roller and surface;
P = O C = re-action of surface, which must be brought into action in a horizontal direction to cause the roller to turn on its axis.

FIG. 50.



CLASS 2.



Class II. (*Fig.* 50).—Suppose the frame in which the roller is carried to be free to move in any direction horizontally, let a force be gradually applied at the centre of the roller A B in the direction perpendicular to the plane of rotation. This will produce no effect as long as it is less than the maximum resistance which can be opposed by friction between the edge of the roller and the surface upon which it rests, that is, as long as

$$R = O\,D\ (\text{Fig. } 50) < S\,\mu.$$

When the force R is equal to S μ, and acts within the angle θ, the roller A B will move with uniform motion along the line of action of the force without turning. The same thing will hold if instead of the force acting perpendicularly to the plane of rotation it acts at some oblique angle to it not exceeding a certain value measured from the normal. The limiting value of this angle depends on the resistance of the friction of the axle of the roller A B to turning. Let this angle be (θ) and draw O E perpendicular to O C, meeting the circle drawn with O as centre and radius O D in E, and let

$$\theta = \text{angle E O D}.$$

When the line of action of the force falls without the angle θ, as, for instance, when it takes place in direction O F, the roller will still slip along the line of the force, but the roller will now also turn. The component in the plane of rotation will now, however, be of a magnitude such that the motion of rotation of the roller is no longer uniform. Since only uniform motion is being considered to take place, the conclusion is, that when the force acts at an angle greater than θ to the axis of rotation (*i.e.* when $a > \theta$) it must never be so great as to cause the roller A B to slip, and therefore only a motion of pure rolling can take place. By proper mechanical devices the roller can be made to turn very easily, and angle θ be kept very small.

The magnitude of the force which must be applied in any position of the roller to effect this motion is

$$P_1 = \text{O K} = \frac{\text{O C}}{\sin a}$$
$$= \text{F} \operatorname{cosec} a,$$

and is at once given by the intercepts drawn from O to C E in the construction, shown in Fig. 50, for any other value of a.

Class 1. (Fig. 51).—Suppose that the frame does oppose restraint, and that this restraint is such as to always cause the centre of A B to move in the direction in which the force acts. Let O F (Fig. 51) lie in this direction, making the angle a with the axis of A B, draw E F perpendicular to O F from the point E, then by the triangle of forces. The force required to move A B is

$$P_2 = \text{O F} = \text{S} \mu \cos (a - \theta)$$

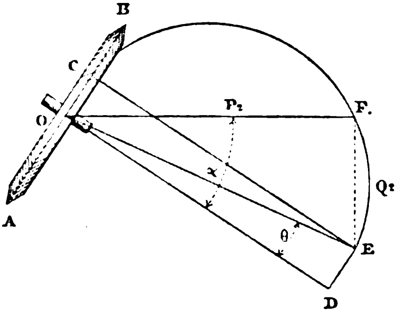
The reaction which is supplied by the frame is

$$Q = \text{E F} = \text{S} \mu \sin (a - \theta).$$

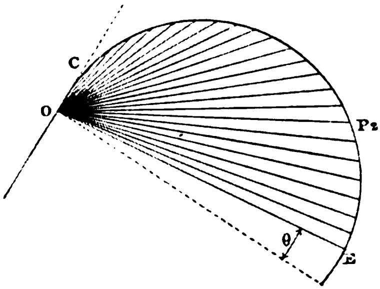
By describing a semicircle upon O E a construction is at once given as shown in Fig. 51, in which by drawing radial lines from O, the value of P_2 for any angle is at once given by the intercept.

The above investigation is by no means a complete one, for this would require a discussion of the moments acting, but having obtained the above result by the more complex method, the Author considered it unnecessary to introduce a more detailed proof than has been given.

Fig. 51.



CLASS I.



Comparing the two foregoing cases by means of the diagrams in Figs. 50 and 51, Diagram A B, it is clear that the forces acting always differ, except in the limiting cases; then

If $\alpha = 90^\circ$ $P_1 = P_2 = F = O\,C$;
$\alpha = 0^\circ$ P_1 is $< S\,\mu$;
P_2 is $\stackrel{=}{>} S\,\mu$.

In order to examine to what extent the assumptions hold good upon which the accuracy of integrators rests, the experimental determination of the following points is needed.

I. Case of boundary measures and limiting case of both classes of area and moment integrators.—The conditions of rolling of two surfaces when the force acts in direction of the plane of rotation.

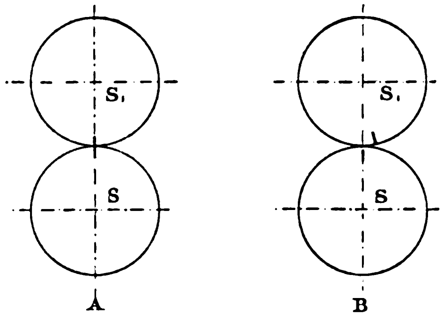
II. Class I. of area and moment planimeters.—Whether the rolling is proportional to the slipping as assumed.

III. Class II. of area and moment planimeters.—Whether there is any slipping in this case, and if so, to what extent.

Case I. There are two separate problems under this head; one where the planes of revolution of the two rolling surfaces coincide; and the other when they do not coincide.

Dr. A. Amsler[1] has experimentally investigated the former thus: Two accurately turned disks, SS^1, (Fig. 52), each 200 millimetres in diameter, were placed with their edges in frictional contact, so that the mark shown on each coincided at the point of contact. By means of the apparatus (Fig. 53) the lower one S was turned by means of a band (BB^1) through 1700 revolutions one way (thus turning the upper one S_1), and then 1700 revolutions in the opposite direction. The marks which should have coincided if no slipping had taken place, were now found to be as in Fig. 52, the marks being a distance $= \epsilon_n = 0 \cdot 05$ millimetre apart. The relative error is thus $= \frac{\epsilon_n}{2\, n\, \pi\, 200} =$ (about) $\frac{1}{40,000,000}$. This experiment is only of value to show the error when the wheel travels back by turning in the opposite direction, and at the most shows that the error is nearly the same in both directions, and does not prove anything with regard to the action of the measuring roller of the boundary measurer; concerning this point observations were wanted upon the

FIG. 52.



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[1] "Ueber den Flächeninhalt und das Volumen durch, Bewegung erzeugter Curven und Flächen," &c., p. 64. Alfred Amsler, Schaffhausen, 1880.

results of the first 1700 revolutions. A very good way of examining the point would be to note the divergence of the marks in x revolutions when S drives S_1, then cause S_1 to drive S back through the same number of revolutions, and it would be seen whether the divergence was due to a difference in the periphery of the wheels, or to a slipping of the surface of contact. During Dr. Amsler's experiments no one was allowed to enter the room, in order to avoid alteration of temperature. He found that the heat radiated from the human body, or even from a lighted candle placed at some distance, had a perceptible influence on the result.

Fig. 53.

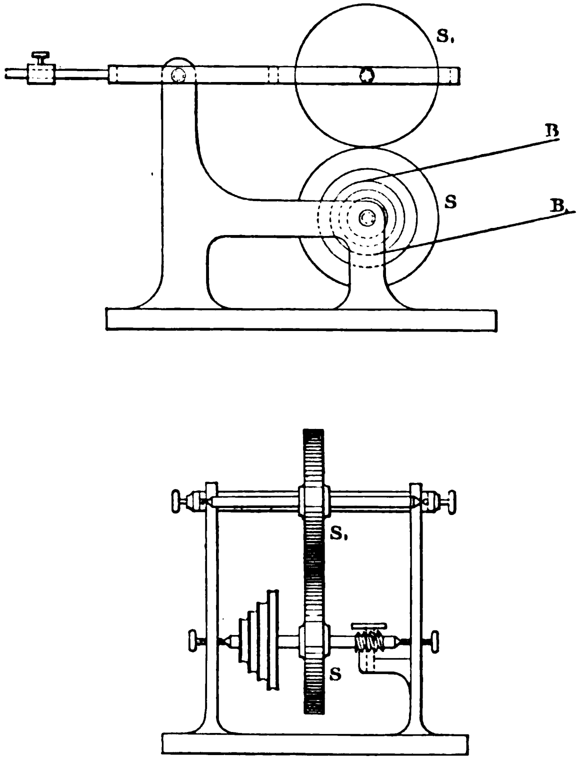


Fig. 54 shows a most important case in which the plane of rotation of the surfaces in contact do not coincide with that of the measuring roller (m) being actuated by the disk M. Fig. 55 shows Dr. Amsler's apparatus for examining this case, in which, if the edge of the roller has any width, there must be slipping action, even though the force always acts in the direction of the plane of rotation.[1]

FIG. 54.

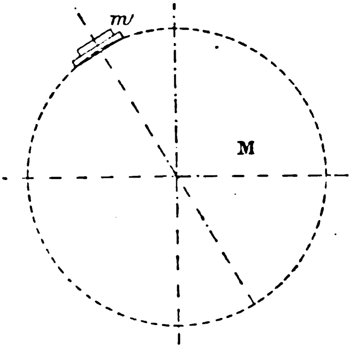
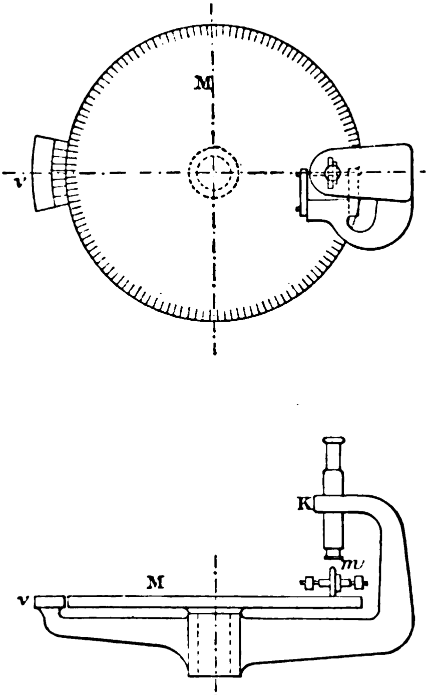


FIG. 55.



The roller *m* which rests on the upper surface of the disk, which latter has its edge divided, and is in juxtaposition with a vernier (*v*). The axis of the roller is fixed, and its edge is thus kept always vertically under a microscope (K). The position of the disk is noted, and it is then moved forward about 8 revolutions (or exactly 2900°), which gives the roller about 130 revolutions, and a mark is observed on the latter. Then in theory the result of giving 8 more revolutions to the disk in the same direction should be to bring the same mark of the roller under the microscope. Practically the successive motions of the disk will be a little different, so that the second advance of the disk will not be exactly the same as in the first case. The same mark on the roller is, however, always brought under the microscope, and the difference in turning of the disk is what is noted.

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[1] "Ueber den Flächeninhalt und das Volumen durch Bewegung erzeugter Curven und Flächen," &c., p. 67. Alfred Amsler, Schaffhausen, 1880.

In the following table—

i = number of experiment,
ϕ = angle by which the disk differs from last reading,

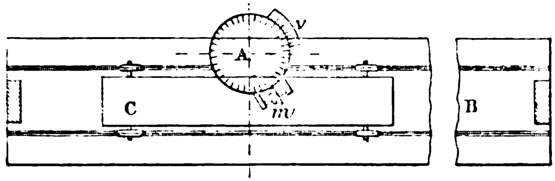
so that the second column gives the positions of the disk at the end of successive advances in which the roller is made to take 130 complete revolutions, the third column shows the travel of disk in minutes (2900° having, of course, to be added to the readings). The fourth gives the difference between these and a mean value. The last gives the ratio of these differences to the travel.

i.	$\phi_i - i\,2{,}900°$.	$\phi_i - \phi_{(i-1)} - 2{,}900°$.	$m - (\phi_i - \phi_{i-1})$.	$\frac{m - (\phi_i - \phi_{(i-1)})}{2{,}900°}$.
	′	′	′	
0	2·58	47·22	−0·06	−0·0000003
1	49·80	47·28	−0·12	−0·0003007
2	37·08	47·34	−0·18	−0·0000010
3	24·42	46·98	+0.18	−0·0000010
4	11·40	47·22	−0·06	−0·0000003
5	58·62	47·04	+0·12	+0·0000007
6	45·66	46·98	+0·18	−0·0000010
7	32·64	47·34	−0·18	+0·0000010
8	19·98	46·86	+0·30	+0·0000017
9	06·84	47·34	−0·18	−0·0000010
10	54·18			

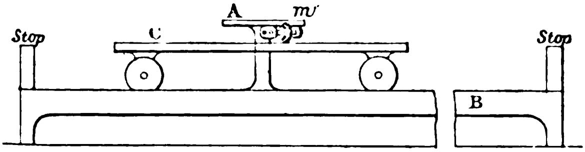
Case II. To test the results when a roller partly rolls and partly slips, Dr. Amsler used the apparatus shown (Fig. 56) in plan and elevation. In this C is a carriage running upon four wheels on the base (B) which has parallel grooves planed in it; the travel of the carriage being limited by two stops at the ends. Upon the surface of C the measuring roller (m) rests, being attached to a plate A. By means of the graduations on A the axis of (m) can be set at any required angle with reference to the direction of motion of the carriage. The frame supporting the roller is carried on the disk by means of pivots, so as to allow (m) to rest on the surface of C with the constant pressure of its weight.

If a = angle of axis of (m) in the direction of the motion the carriage;
s = motion of the carriage;
u = turning of the roller;

Fig. 56.



PLAN.



ELEVATION.

$$\text{Then } u = s \sin a = s \cos\left(\frac{\pi}{2} - a\right) = s \cos \beta.$$

If ϕ = actual reading of vernier v;
and $\phi = \phi_0$ when $a = 90$ or $\beta = 0$;
then $u = s \cos(\phi - \phi_0)$,
$u_1 = s \cos(\phi_1 - \phi_0)$,
$u_2 = s \cos(\phi_2 - \phi_0)$, etc.;

$$\text{Then } \tan \phi_0 = \frac{u_1 \cos \phi_2 - u_2 \cos \phi_1}{u_2 \sin \phi_2 - u_1 \sin \phi_1},$$

$$s = \frac{u_1}{\cos(\phi_1 - \phi_0)} = \frac{u_2}{\cos(\phi_2 - \phi_0)}.$$

In the following Table, which represents the results of experiments when the disk was covered with a surface of pear-tree wood, carefully polished (paper being, however, found to afford almost as good results)

i = as before, the number of the experiment;
B_i = angle of inclination of roller for experiment (i);
u'_i = motion of roller as observed for experiment (i);
u_i = motion of roller as calculated.

i.	$\beta_i = \phi_i - \phi_o$.	Experiment u'_i.	Calculated u_i.	$u_i - u'_i$.
	° ′ ″			
0	0 0 0	9,649	9,649	0
1	8 9 36	9,552	9,551	−1
2	9 36 0	9,511	9,514	+3
3	26 9 36	8,657	8,661	+4
4	27 36 0	8,550	8,551	+1
5	44 9 36	6,916	6,922	+6
6	45 36 0	6,750	6,751	+1
7	62 9 36	4,505	4,506	+1
8	63 36 0	4,290	4,290	0
9	80 9 3	1,650	1,649	−1
10	81 36 0	1,415	1,410	−5

Case III. The actual conditions of motion when a force smaller than the component of $S\mu$, acts obliquely to the plane of rotation of the measuring roller, do not appear to have been made the subject of direct experiment. It is apparently always tacitly assumed that no slipping takes place. But this crucial point cannot be thus left to mere conjecture, and the Author has designed a method of carefully testing this which he has not yet been able to properly carry out. From a few rough observations there seems little doubt, however, that some slipping always does take place, and that its amount is in the limiting cases by no means inconsiderable.

Lastly, a few words may be said concerning the work of Professor W. Tinter, and of Professor Lorber. The former has examined[1] most carefully no less than nine different planimeters, from which he concludes that the different angles at which the measuring roller of the polar planimeters turn has little effect upon the result, and that taking one turn of the measuring roller as $f = 100$ square cm., the average error in the reading was only from $= 0 \cdot 00075$ to $0 \cdot 0013$, according as the centre of rotation was without or within the area to be measured. The work of Professor Lorber is so extensive and elaborate that it is impossible to do more than give in the most brief form the results at which he has arrived after many thousands of experiments. He concludes that error in the reading is always represented by an equation of the form—[1]

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[1] "Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereins," vol. xxix., 1877, p. 154.

$$d\,n = \mathrm{K} \cdot + \mu \sqrt{n},$$

$d\,n$ = the error in the reading, K and μ being constants,

where n = the reading of the measuring roller;

the above equation gives rise to one of the following form:—

$$d\,\mathrm{F}_n = \mathrm{K} f + \mu \sqrt{\mathrm{F} f},$$

where F = actual area to be measured,

and $d\,\mathrm{F}_n$ = the error in the result expressed in terms of the area.

The following are the results given in his latest paper—[2]

Linear planimeter. . . $d\,\mathrm{F} = 0 \cdot 00081 f + 0 \cdot 00087 \sqrt{\mathrm{F} f}$
Polar planimeter . . . $= 0 \cdot 00126 f + 0 \cdot 00022 \sqrt{\mathrm{F} f}$
Precision polar planimeter $= 0 \cdot 00069 f + 0 \cdot 00018 \sqrt{\mathrm{F} f}$
Freely swinging planimeter $= 0 \cdot 00060 f + 0 \cdot 00026 \sqrt{\mathrm{F} f}$
Simple plate planimeter . $= 0 \cdot 00056 f + 0 \cdot 00084 \sqrt{\mathrm{F} f}$
Rolling (Coradi) planimeter $= 0 \cdot 0009\ f + 0 \cdot 0006\ \sqrt{\mathrm{F} f}$

The degree of accuracy represented by these results may be inferred from the fact that in one case of the last planimeter when

$f = 100$ the relative error $= \dfrac{d\,\mathrm{F}}{\mathrm{F}} = \dfrac{1}{13{,}330}$.

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[1] "Ueber die Genauigkeit der Planimeter." Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxxi., 1883, p. 22.

[2] "Ueber das Roll-planimeter von Coradi, von Franz Lorber." Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereins, vol. xxxvi., p. 135.

[DISCUSSION.

Discussion.

Sir Frederick Bramwell.

Sir **FREDERICK BRAMWELL**, President, said that the Paper having been read only in abstract, there had been no mention whatever of what the Author himself had done. The members would no doubt, under the circumstances, allow him considerable latitude in personally explaining the apparatus on the table. He would not, however, ask them to defer the expression of their thanks to Professor Shaw for his valuable Paper until this explanation was given; but he felt sure that after this was done it would be still more clear that those thanks were well deserved.

Professor H. S Hele Shaw.

Professor H. S. **HELE SHAW** said that the Paper had been only read in the form of a brief abstract because from the nature of the subject, and its method of treatment, it appeared advisable that he should personally give a short account of its contents. The engravings, of which there were a good many, could not be prepared in time to be sent to those who were likely to take part in the discussion, and therefore he would explain the principal points which he believed to be original, and which he hoped would be thoroughly discussed. He would take this opportunity of thanking Professor Amsler for kindly lending him several instruments, some of which were now shown for the first time in this country, having been sent from Switzerland for the purpose, at Professor Amsler's own expense. He also wished to thank Mr. C. V. Boys for lending him models of his tangent integrators, and also two of the actual instruments to exhibit; and his friend and colleague, Mr. C. D. Selman, for several valuable suggestions and assistance in the preparation of some of the diagrams. The Author then proceeded to explain, by means of the diagrams on the walls, and by models which had been constructed on a large scale, the principles of the classification adopted in the Paper and the various instruments exhibited.

Mr. Anderson.

Mr. **WILLIAM ANDERSON** (of Erith) observed that he had had considerable experience with continuous integrators in measuring work done by agricultural implements. There was a good deal to be said about the use of those instruments and the defects to which they were liable, about the personal error, which was an important point, and errors from imperfect adjustment. The conclusion at which he had arrived with regard to continuous integrators in which the space passed over and the strain were multiplied together and registered continuously, was that they were exceedingly good for comparative results, but were not altogether to be trusted for positive indications. In comparing, Mr. Anderson.

for example, a number of machines working in a field under similar circumstances as to weather and everything else, with the same operator, the comparative results would be trustworthy; but if there were any variation in any of the conditions, they would not. There was always a good deal of doubt about the positive results. The causes of error were these. In the continuous integrators the integrating wheel was attached to a train of wheel-work which possessed a considerable amount of inertia and friction. In planimeters and integrators of that class, where the observations could be made slowly, at a steady speed, and where the conditions did not vary, inertia did not count for much; but in the steam-engine, and in agricultural implements or in traction indicators, there were great and rapid variations of speed. The sudden strains which were put on by the tractive force shifted the integrating wheel along the disk suddenly, and the speed changed in a similar manner. The force necessary to accelerate the movement of the integrating wheel and its mechanism tended to cause a slip, which was partly counteracted by a slip produced by the force necessary to arrest its motion when the speed changed, but the friction of the mechanism always acted in the same direction, tending to augment the error. With one implement, for example, if there were a tolerably steady pull with no sudden variation in the velocity, there would be one amount of error, whereas if another implement were worked in a jerky fashion there would be a totally different amount of error. With regard to personal error, to which the Author did not attach much importance, he had reason to think that it was of great consequence. The degree of care and skill exhibited in adjusting the instrument and taking the measurements had an important influence; he was therefore always careful, in a series of experiments with agricultural implements, to have the same observer throughout, if possible, because the results aimed at were rather comparative than positive. Still he was bound to say that, with care and experience, satisfactory positive results could be attained. The Author did not appear to be aware of the extensive use which the Royal Agricultural Society had made of the integrator which had always been known as Morin's, but it appeared that honour had been ascribed where it was not strictly due; probably the reputation of the great French mechanic, who had done so much to introduce it, had obscured the claims of the real inventor. For the last thirty-five years the Royal Agricultural Society had used continuous integrators, and he thought that there was no one more competent to speak of their action than Sir Frederick

Mr. Anderson. Bramwell, who had himself conducted many of the experiments. The issues had often been very important, involving the fortunes of manufacturers of agricultural implements, which had, in a great measure, hung upon the indications of the dynamometers. Most of the apparatus used by the Royal Agricultural Society had been designed and constructed by the late Mr. C. E. Amos, M. Inst. C.E., and by his son Mr. J. C. Amos, who for many years filled the office of Consulting Engineers. With reference to continuous indicators for steam-engines, he had little or no experience. He had tried them, but the results had not been, so far, satisfactory. One of the chief defects was the difficulty of keeping the little integrating wheel perfectly free from flats. It was not easy to find any metal perfectly uniform throughout; and if it were not uniform, a flat would soon form, and then all the results would be utterly untrustworthy, because the wheel tended to hesitate at the flat place. Formerly integrating wheels were made of gun-metal, cast with great care, and under a great deal of head. Latterly they had been made of steel, and a better result had been obtained. But even when the wheel wore uniformly, if the width of the surface in contact with the disk varied, then again there was a source of error, because the surface of the integrating wheel lying upon the disk became greater, and then there was uncertainty as to the true diameter of the periphery of the disk on which the integrating wheel was working. The only way of eliminating these errors was by repeated testing of the apparatus.

Mr. Boys. Mr. C. VERNON BOYS said the first part of the Paper on which he desired to say a few words was the division of the subject into different classes. The Author had referred to one system of classification which Mr. Boys had adopted in a Paper published in the 'Philosophical Magazine,'[1] a division into three classes. The Author had rightly shown that the two classes which Mr. Boys had called the "radius class," and the "Amsler class," were in a mechanical sense, that was so far as the connection between the surface of the integrating wheel or roller and the surface on which it worked was concerned, absolutely identical. But though that was undoubtedly the case, he thought the division might still hold good, for an inventor could not have contrived machines in one class or in the other without having had some such system of division in his mind at the time of the invention. There was one considerable omission in the Paper, and that was the only point on which he felt it necessary to find

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[1] Vol. xiii. Fifth series. 1882, p. 77.

Mr. Boys.

fault. There was no mention of a very large series of most beautiful machines, designed and he believed partly constructed by the Author himself. As those instruments had been fully described in a Paper by Professor Shaw before the Royal Society, possibly he thought that they were so well known that it was unnecessary to describe them again; but it would certainly have rendered the Paper far more complete and valuable if that large amount of work had been incorporated in it. Of all the instruments brought before them he thought that the new precision planimeters and that extraordinary spider-looking instrument crawling on the sphere were those which called for the utmost admiration. It was impossible to look at them or to use them without being impressed with the extreme mechanical beauty of their construction and design. But though that was undoubtedly the case, he thought that no one could see some of the combinations of a sphere with three, eight, or six little wheels round it, inventions of the Author, without classing them even above those instruments in point of beauty.

The Author had spoken of the tangent principle as being a particular case of machines which worked without slipping. This was perfectly true; but there was a very great distinction between integrators depending upon the tangent action and integrators depending upon a rolling action of the radius class, to which alone the other machines belonged. There was one accidental mistake in the wall diagrams representing two spheres[1] which he desired to point out, as it was a little puzzling. In the instrument of Clerk Maxwell, one of the non-slipping radius class, the axes of the two spheres were shown in such a position that rolling would ultimately make them coincide. In reality the equator of one rolled over the pole of the other, as was obvious to those who had anything to do with integrators. The distinction between instruments of the tangent class and those of the radius class might be represented by the little wheel of the instrument. The accuracy of integrators of the radius class depended upon the exact size of the wheel, and the exact size of the surface upon which it rolled; and, as Mr. Anderson had remarked, it was very much impaired when flats formed upon any of the surfaces in contact, for there was then a little hesitation. The mere action of integrating-machines in which there was slipping was sure to produce those flats at some time or other, so that the time they were likely to last and the amount of work they were capable of doing were limited. The actual size of the roller was

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[1] This has been corrected in Fig. 33.—Sect. Inst. C.E.

Mr. Boys. of importance, for as it wore and became gradually smaller, the number of rotations were affected, and therefore the recorded result gradually increased. These were the objections to instruments of what he had called the radius type. In the class of instruments at which he had worked exclusively, and which he believed he had originated until he found that to a certain extent Mr. B. Abdank-Abakanowicz had preceded him, the wheel was allowed to roll along just in the direction in which it was pointing. Any one who had been in the streets of London must have noticed with what extraordinary persistence and power the wheels of all vehicles went in the direction in which they were pointing. A butcher's cart driven round a corner with tremendous fury would often, in spite of its jumping on the ground, still continue its course with very little side slip. If the springs were sufficiently good, or the road was sufficiently smooth, so that the wheel kept in contact with the ground, it would apparently not slip at all. In the case of the first instrument which he had made, which he had called the cart integrator, he was astonished to find with what extraordinary accuracy results were obtained by its use, such for example as the area of a circle and other things that were known. In that instrument he had depended entirely upon the fact that the steering-wheel of a tricycle would go along in the direction in which it pointed. The instrument had to pull a heavy brass-cart after it and slide in a comparatively roughly made groove, but even so he found the value of π on squaring the circle came out 3·14 when using a very rough home-made instrument. It seemed, then, that if the sources of side-slip which were undoubtedly present, due to the great friction that had to be overcome in dragging the cart, could be removed—that was, if the ground under the cart could be made easily movable, which was the case when it was converted into a cylinder, the cylinder would follow exactly in the direction in which it should go. For that reason an integrator of that class was free from the objections which had been raised, that in time integrators wore out, the little wheel got flats upon it, and as the size varied the record varied. In the case in point there was no slipping and no tendency to make flats, and if the wheel was made half or twice the size the record was the same, for it only depended on the direction in which it wanted to go, not upon the amount that the wheel turned in going along in that direction. He desired to say a word or two with regard to an instrument, his engine-power meter, which was not so well known as he had hoped it might be. There were certain sources of error apparently present in it, but which were

Mr. Boys. really imaginary. In the first place, it would seem that if the position of the piston-rod, and, therefore, the angular position of the little tangent wheel G varied in the least, then as the cylinder H travelled along there would be an error due to the angular want of true precision. But that was not so, for supposing the spring to be too long or too short, and the tangent wheel to be permanently deflected, when there was no steam-pressure, at an angle, say, of 2° or 3°, then as the cylinder moved in one direction, the wheel would run up a certain slope, and when the cylinder moved in the other direction, it would run back along the same slope, and so far as that was concerned, no error would be introduced. The wheel might be set at a permanent angle, and the roller work backwards and forwards, and nothing would be recorded at the end of the operation. He could show it with a rough paper and wood model. If he permanently compelled the tangent wheel to assume a certain angle by holding it with his thumb, as the cylinder travelled in one direction it would rotate a certain amount, and when it travelled in the other direction it would rotate back again, and on the dial there would be no permanent record. The disk-cylinder integrator had one serious defect; it was very difficult to apply it to cases in which growth of time or of motion was continuous. If it was desired to have a time-integral and a motion-integral, when the motion was continuous, it could not be easily applied, because when the cylinder had got to one end of the stroke, there was nothing for it but to stop and come back again. It was, therefore, necessary to apply a mangle-motion, so that as the motion was continuous the cylinder went backwards and forwards; then by causing the cylinder to work between two tangent wheels alternately, or by letting the mangle-motion work ordinary reversing gear between the cylinder and the recording mechanism, continuous integration could be effected. But of course the instrument, where continuous integration was concerned, would not compare with the spherical integrators designed by the Author. On the other hand, he did not think that any instrument, in the peculiar case presented by the automatic integration of an engine-diagram, could compare with it, for those peculiarities of motion which interfered with the ordinary form of radius machines by causing a perpetual scrubbing, to which reference had been made, produced no trouble at all, for there was no side-slipping, and because the very large moment of the radius integrator was replaced by the extremely small moment of a little cup containing a wheel not the size of a three-penny bit, and by a little bar of steel. In fact, Mr. Boys. the moment of the piston and its attachments was nothing like so great as that of an ordinary Richards' indicator, because there was no multiplication of motion.

Mr. Anderson. Mr. W. ANDERSON wished to state that he had been able to bring to the meeting the integrating part of one of the old dynamometers of the Royal Agricultural Society. The date of its construction was unknown, but he believed it was about the year 1848.

Mr. Mair. Mr. J. G. MAIR observed that the Author had not given himself sufficient credit for the machine he had invented, and he would like to ask him if the reading of the counter gave such accurate results as the vernier on Amsler's planimeter. To read by means of a counter was of great advantage, and especially so where large numbers of indicator-diagrams had to be taken out; on some of the engine trials he had made, three hundred diagrams had to be averaged, and constantly reading the vernier on Professor Amsler's instrument was trying to the eyes. The application of the integrating machine as a power-meter was a most useful one, and he had made several trials with the one invented by Mr. C. Vernon Boys; on three trials the readings were 68·5, 68·2, and 73 by the meter, against 67, 67·5, and 72 in the pump. The pump-power was taken from the displacement of the pump-piston, and the head as shown on a mercury gauge. He thought those results were a proof of the correctness of the instrument. He did not think that reading a counter was more difficult than reading the dial of a watch. One other measurement had to be made, namely, the distance between the stops, and as that could be measured with an ordinary rule, a child could almost make the simple calculation, so that he did not think personal error very much affected such an instrument. There was naturally a good deal of diffidence in using a machine, the details of which were not thoroughly grasped. With an indicator-diagram, there was something to see which was readily understood; but where compound measurement was shown on a counter, it was at first difficult to realize the reading as correct. As soon, however, as the instruments were better known, he had no hesitation in saying that, where the absolute shape of an indicator-diagram was of no consequence, the continuous integrator would entirely supersede all other means of measuring power.

Mr. Halpin. Mr. DRUITT HALPIN said that the Author had (p. 88) referred to one of the minor improvements by putting a locking-spring to the frame. Mr. Mair had noticed the great difficulty there was in reading the instrument, on account of the small scale to which it was graduated, but the Author had not completely followed the idea of adding the locking arrangement. The convenience of reading the instrument was doubtless very great, for it could be taken up and put in a good light, but the real object of the locking gear was to make the instrument do its own addition, and also carry over the decimal places now lost. Instead of taking each diagram by itself, and writing down the result of each separately, and adding them up, the instrument was set at 0 and locked; the instrument was run over the diagram, and it was locked, and so on. So that by taking ten diagrams successively, and putting the decimal point one point back, the instrument was made to do its own addition. It had the further advantage that, whatever the last decimal might be, it was carried on by the instrument. If it was 2·38, it could not be said whether it was 2·389 or 2·381. With regard to Mr. Boys' application of these instruments, he had had an opportunity of testing it on an engine of 120 or 130 I.HP., and he found the results coincided within from 1 to 2 per cent. of the indicated power which was obtained with standard indicators. With Mr. Webb's permission, he also put one of his power-meters on the large rail-mill at Crewe, and took a series of observations there of the exact power required to roll a rail, from the moment the ingot touched the rolls to the moment the next ingot touched them, which gave the true power, correction being made for any difference of velocity in the fly-wheel. It gave the power both while the engine was running with the bloom in the mill, and when it was running empty. Whether the machine in its present form would be suitable for locomotives, he was hardly prepared to say, because he feared that the attachment which was provided for taking diagrams, was perhaps so heavy that its inertia would interfere with the correct action of the instrument. But, if that was lightened, or the attachment left out, he was sure the best results would be obtained from it. Mr. Halpin.

Mr. H. Cunynghame said that his attention had been called a great deal to Mr. Boys' machines, in the development of which he had assisted, as they were first designed for practical application to steam-engines. He had made many attempts to apply continuous integrators for the purpose of integrating electric power, and he certainly could safely bear out all that Mr. Anderson had said about the imperfections of integrators of the slipping type. If a wheel was running in any direction in which it was likely to slip upon the surface, it would be rubbed into facets, and in like manner a sphere would be rubbed into a polyhedron. In this state both wheel and sphere would be worse than useless for integration. But if these machines had an integrator of the roller type, even if Mr. Cunynghame.

Mr. Cunynghame.

it had facets already, the rolling would take the facets out of it just as an apothecary rolled his pills. Instead of an integrating wheel of hard steel, as was necessary in all integrating machines of the slipping type; in those of the rolling type, soft metal might be used, and the more it was used, the better it would get. Moreover in such machines, since what was counted was not the revolutions of the wheel, but the revolutions of something caused to roll by means of the wheel, the accuracy of shape of the rolling wheel became of minor importance, and even if it "skated" over the surface instead of rolling a fair result would be obtained. He thought Mr. Anderson's remarks were somewhat unjust to planimeters of the rolling type, which he did not think had been brought before the public so as to be within the experience of any one. That led him to say a few words on Mr. Boys' steam-power meter. He believed that Mr. Boys and he were the first in this country to make a trial of those machines. They made a trial at the works of Messrs. Ransome and Jocelyn at Battersea, and for that purpose they had an extremely good indicator made by Messrs. Elliot. It would be quite understood that Mr. Boys' indicator was not in any way calibrated by mere trial. They took the measurements of the engine and the diameter of the cylinder. Then they took the amount by which a certain pressure of steam would cause the spring to rise, just as was done before taking the HP. by means of a Richards' indicator. They thought that if those two machines were used upon the same engine, and if the results given by the two machines, namely, Richards and Boys, were independently calculated from the constants of the two machines, then if these results nearly corresponded, a very remarkable coincidence of testimony would be obtained. They therefore put Boys' machine on the engine alternately with Richards', and he thought they must have alternated twenty times, and the results of Boys' machine were found to be uniformly during the first series of experiments about 23 per cent. too high. That puzzled them extremely, but upon examination they found that the manufacturer, instead of making the piston 1 inch in diameter, had made it 1 square inch in area, and when they made the proper correction they found the results to agree to about 1½ per cent., and with those stated by Mr. Halpin and Mr. Mair. Mr. Mair's tests were made in this way: he raised, by means of a pump, a given weight of water through a number of feet, and then he estimated the foot-pounds and compared them with one another, and the result showed a remarkable degree of accuracy, the discrepancy of 1 or 2 per cent.

being accounted for by the loss of work owing to the raising of the pump-valves, which were large and heavy. Mr. Cunynghame.

Dr. Pole. **Dr. William Pole**, after testifying to the high character of the Paper, offered a few remarks on the very early example of mechanical integration with which the Author had connected his name. It had come about in the following manner. Some half-century ago, the engineers of the centre and north of England became aware of the reports published from time to time of the extraordinary economy of the pumping-engines of the mines of Cornwall. These reports at first obtained no credence, and even when they were found to have some foundation, the most singular attempts were made to explain them away. In the midst of the controversy, the late Mr. Thomas Wicksteed, M. Inst. C.E., the Engineer to the East London Water-works Company, determined to throw light on the question by buying an engine in Cornwall, and setting it up to pump water on his own premises at Old Ford, where it could be thoroughly tested and examined.

The subject had previously been brought before the notice of the British Association for the Advancement of Science, and had attracted the attention of Professor Henry Moseley. He, in writing his excellent work on "The Mechanical Principles of Engineering and Architecture," had become acquainted with a principle of dynamometrical admeasurement proposed by Mr. Poncelet, and carried out in 1838 by General Morin; and it occurred to him that a machine might be contrived on a similar principle, applied to record the work done by a steam-engine, by a species of mechanical integration, combining the pressure exerted on the piston with the space moved through; and it was seen that such a machine would be most usefully applied in testing the performance of Mr. Wicksteed's Cornish engine.

At the meeting of the British Association in 1840, a grant was made for the purpose, and a committee, consisting of Professor Moseley, Mr. Eaton Hodgkinson, and Mr. J. Enys, was appointed to carry it out. The machine was constructed under Professor Moseley's direction, and a full account of it was given in the Report for the following year. The trials were then made on the engine, and the results were exceedingly satisfactory. The integrator worked for a month without intermission, and its indications, when calculated out, were found to agree closely with the results obtained, as accurately as they could be, by other means.

The fixed data of the engine had all been well ascertained, but, to render the comparison complete, it was found desirable to get, if possible, an accurate measurement of the velocity of the piston

Dr. Pole. at various parts of its stroke; this velocity was very variable, depending not only on the mass in motion, but also on the ever-varying force of steam acting on the piston, and no means had hitherto been devised for ascertaining the velocity experimentally. The attention of the Committee had, however, been directed to an admirable chronometrical instrument contrived by Messrs. Poncelet and Morin, and Professor Moseley undertook to adapt a machine on this principle to the Old Ford engine.

At this time Dr. Pole (who had been occupied independently in investigating the action of the Cornish engine) had the honour of being invited to join the Committee, and the two succeeding Reports, in 1843 and 1844, were written by him.

By means of these two instruments, and by an ordinary indicator, aided by careful observations as to the consumption of coal and water, and other variable factors, the working of the Old Ford Cornish engine was investigated, both theoretically and practically, in a most complete and accurate manner, and the peculiarities of this form of engine, as compared with the ordinary engines in use at that time, were thoroughly brought out,[1] so as to clear up all the doubts that had been so long entertained by engineers. This application of a mechanical integrator to real work of magnitude and importance was probably the earliest made. It was intended to follow it up by adapting the machine to other purposes, especially to ocean-going steamers, and it was actually fitted to the engines of the "Great Western" steam-ship, on her first voyage, but by an accident which it was difficult to repair at sea, the experiment was rendered useless, and the attempt was never renewed.

Mr. Bousfield. Mr. W. R. Bousfield said he had not had the advantage of reading the proof of Professor Shaw's Paper, but he had heard it read in its short form at the previous meeting, and he thought possibly it might be of interest, and useful in connection with a Paper which dealt, more or less, with the different types of mechanical integrators, if he mentioned a principle which, so far as he knew, had not been alluded to. It occurred to him some years ago that, by the use of various curves in connection with planimeters, various products and squares might be readily integrated. A simple form of area-planimeter of this kind might be made by combining a T square and a set square, or two set squares. Referring to the

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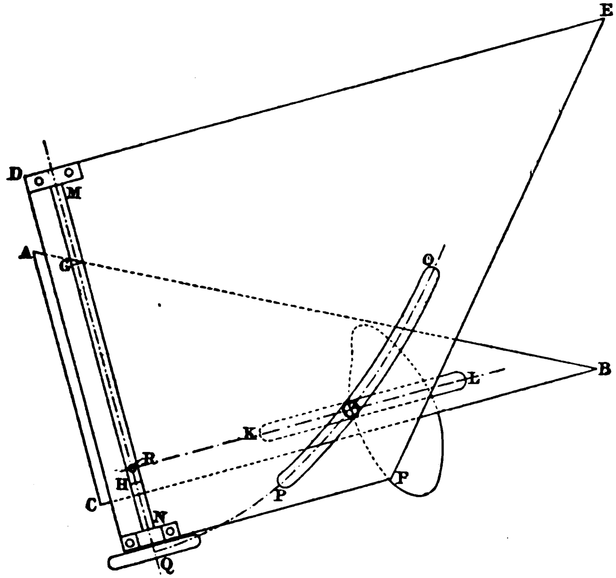
[1] This investigation was afterwards published in "A Treatise on the Cornish Pumping Engine. By William Pole. Part iii., Analytical Investigations. Weale. London, 1848."

Mr. Bousfield.

illustration, Fig. 57, the lower T square or set square A B C would have in it a slot K L and upon it a rib G H, and would be capable of motion about a point R in line with the slot. The upper set square would have a slot M N capable of sliding upon the rib G R, and also a parabolic groove O P. A pointer—in practice a ring with cross wires—would slide in the slots K L and O P. In using this planimeter a needle point would serve to pin the lower set square through the point R, at a convenient pole in relation to the area to be integrated. The cross wires or pointer would be carried round the curve enclosing the area to be integrated, the two set squares at the same time sliding on one another by means of the rib G H and slot M N. The measurement would be made by the

FIG. 57.



AREA-PLANIMETER.

roller Q placed at the vertex of the parabolic curve. The principle of the apparatus was very simple. Taking polar co-ordinates, with R as the pole, the area to be integrated could be expressed as

$$\int \tfrac{1}{2} r^2 \, d\theta.$$

If now the equation of the parabolic slot were

$$y^2 = 4 a x$$

Mr. Bousfield. and the parabola moved, as in the apparatus, so that y was always $= r$ the expression for the area would become

$$\int 2\, a\, x\, d\, \theta$$

This showed that the area was measured by the roller Q at the vertex of the parabola. This proof rather suggested that possibly the use of polar co-ordinates in some of Professor Shaw's proofs would shorten them. By the use of other curves, instead of a parabola, the principle could be applied to the mechanical solution of various problems in integration.

Professor Hudson. Professor W. H. H. Hudson remarked that the classification adopted by the Author coincided, if not entirely, very considerably with this, that in the instruments in which slipping was bound to take place, when it was attempted to express the element of area, in mathematical language $y\ dz$, dz corresponded to the angle turned through and y to the radius, so that the area corresponded to the length. That was certainly so in some of the earlier instruments; but those in which no slipping was allowed to take place seemed to correspond rather to a different mode of translating the mathematical expression. There was a certain amount of turning which was proportionate to dz, and then by a suitable mechanism that was turned into something else proportional to $y\ dz$ by using a multiplier proportional to y. One wheel was made to turn so many times faster than another, the number of times corresponded to y instead of, as in the first class of instruments, the radius being proportional to y. That multiplier occurred in the various forms of the instrument, sometimes as a sine, and sometimes as a tangent. Those of the sine class would have this disadvantage, that the multiplier must of necessity be a proper fraction. That would limit the range, whereas those dependent on the tangent seemed to have no limitation whatever, and the multiplier might be anything. This seemed to be a great advantage of the sphere instrument of Professor Shaw, that there was, apparently, no limitation at all, that which represented y being a multiplier which represented a tangent. He had always taken great interest in mechanical illustrations of mathematics. In most cases the mathematics had been incidental, but in this case it was of the very essence of the whole business. These were instruments designed to illustrate not only mathematical results, but even mathematical processes, and he was very much struck by the way in which the Author had developed Amsler's planimeter out of the simple form of the disk and roller. It illustrated a mathematical conception which was sometimes received with incredulity by those who met with it for the first time, namely, treating parallel straight lines as meeting in a point at infinity. This was done in pure mathematics, and he found that the Author had been obliged to do it in order to bring his instruments all under one head. It seemed to him that this was a striking illustration of the inter-action of mathematics and mechanics, and the benefit which each gave to the other. Professor Hudson.

Mr. W. E. Rich said the integration of the areas of plane surfaces, which these instruments were ordinarily designed to do, was much less difficult than the integration of work done on a dynamometer in the manner spoken of by Mr. Anderson. One of the great desiderata in dynamometrical measurements was to get a spring which followed Hooke's law; but unfortunately in practice they never got one that followed it precisely. The next thing was to adjust the instrument for zero. If the instrument were not accurately so adjusted, complex formulas had to be used for reducing the results, and as in many instances zero was not accurately determined, and these formulas were at the same time overlooked, the results recorded were in such cases very erroneous. One point of practical difficulty with integration for a dynamometer was the slipping of the small disk upon the large one. In the field, when it was raining, the observers were much hampered in that way, and on a stony road when travelling at a high speed with a small integrating disk, the contact between the disks was frequently broken by the shake and jar of the whole instrument. These observations were perhaps not directly pertinent to the question of integration; but one of the most useful objects of integration was for dynamometrical purposes, and therefore he thought it worth while to mention them. Mr. Rich.

Professor H. S. Hele Shaw in reply said that the question of Mechanical Integrators was a very much wider one than many would at first think; but the discussion upon the Paper had embraced two principal points: Planimeters such as were shown upon the table, and the subject of Continuous Integrators. The slipping class of Planimeter had been brought to a great state of perfection, and their accuracy was, as he had shown, remarkable. It seemed to him that the only objection to them—an objection which several speakers had adverted to—was the difficulty of reading them. Most of the remarks had been devoted to Continuous Integrators. Perhaps that was not altogether unnatural, because they had, as Mr. Rich had pointed out, such a directly practical application. Mr. Anderson had given valuable testimony on the subject of the defects of such instruments Professor H. S. Hele Shaw.

Professor H. S. Hele Shaw.

as were in use for dynamometrical purposes, and his experience agreed with that of Mr. Rich and of all who had much occasion to use them. Professor Shaw thought the general conclusion was that none of the Continuous Integrators in use for this purpose were really satisfactory in their action. To say of an instrument of measurement that it was not an accurate instrument, that it was merely capable of giving comparative results, was after all to give it very poor praise, for mere comparative results simply meant that no constant for the instrument could be obtained. He had no doubt that, for temporary purposes, the difficulties might be overcome, but it was the general opinion that an instrument like the disk and roller, which, by the way, in spite of what Mr. Anderson had said, *was* first applied by Morin after its invention by Poncelet before 1840, was not reliable when in continuous use. An instrument that worked one day differently from another day, because the conditions were slightly changed, must certainly be pronounced to be very imperfect. It was because of this very difficulty that he was led, as he had no doubt Mr. Boys and others had been, to work at the subject, and to endeavour to overcome the difficulty of the slipping action. Mr. Mair, Mr. Druitt Halpin, and Mr. Cunynghame had all testified to the satisfactory action of the tangent-integrator of Mr. Boys, which was one solution of the problem of avoiding the slipping action in question, but had been employed in a far more trying application than with a dynamometer, viz., as a steam-engine integrator. This he was very glad to hear, because the instruments of his own exhibited on the table depended upon the same principle for their successful action, and it was just in this particular that they differed from the integrator referred to by Dr. Pole. His instruments had been alluded to in complimentary terms by one or two of the speakers, and perhaps he might be allowed briefly to describe the principle upon which they worked, and also to call attention to two new instruments which were shown for the first time on the previous Thursday at the Royal Society. The difficulty which he endeavoured to overcome was to make use of those mathematical properties of the sphere, which he had previously discovered and published, and which Professor Hudson had alluded to as to sine and tangent forms. As was not surprising, he had found, when he came to collect information on the subject, that the same properties had been employed by others, amongst whom were Professor Mitchelson and Professor Amsler. But what the Author had endeavoured to do was to avoid the slipping of the measuring-roller over the integrating sphere. That was his first thought. There was generally

Professor H. S. Hele Shaw.

a germ in all inventions, and that was the germ of his. If instead of moving the measuring-rollers round the sphere they could keep them in contact with the sphere, and move the axis of the sphere, or, as it at first occurred to him, have the two rollers in contact and roll them round the spheres, they would hold it in such a way that they would allow it to rotate round the different axes in the solid. At first he did not think it would work, but he tried it with a rough boxwood ball, and two disks with india-rubber rings around them, and he was surprised to find that the rollers did move round, and to see the ball rolling round on a different axis. He thought at first it was merely a question of rolling centres, but after some time he saw that it was really a question of geometrical principle, and having certain rollers in contact round one equator it did not matter where they were placed so long as the others were perpendicular to the first, acting in fact on the same principle as that by which two bevelled wheels would work together. The axis of rotation round which the sphere must turn, because of the contact of the other set of rollers, was in the vertical plane; there was but one intersection of the two planes, and that intersection was the axis of rotation of the sphere. That principle once understood enabled him to construct various other models based upon it. He was indebted almost entirely to his brother, Mr. Edward Shaw, Stud. Inst. C.E., and to Mr. W. E. Kerslake, for working out this in a practical form, and constructing the various instruments exhibited. One of these instruments was a continuous integrator, which had been designed for application to the dynamometer of the Rev. F. J. Smith, of Taunton, who intended to have been present and take part in the discussion, but from whom he had just received a telegram stating that he had tried it most carefully and exhaustively, and had found that it had given absolutely uniform results. He had tried it himself, but it was a very satisfactory thing that it went to Mr. Smith straight from the hands of the maker, not adjusted in any way. It was remarkably simple. According as the arm was moved into a more or less inclined position, so there resulted a larger or smaller travel of the indicator. No appreciable effort was required to turn it; it was done with a minimum of power, and it entirely got over the difficulty of unequal wearing. He had every reason for thinking that if anything it would rather tend to wear the ball round than otherwise. Another instrument that he had on the table was the moment-integrator. Professor Amsler's moment-integrator was an expensive one, and at the time of writing the Paper he had not any idea of constructing one; but

Professor H. S. Hele Shaw.

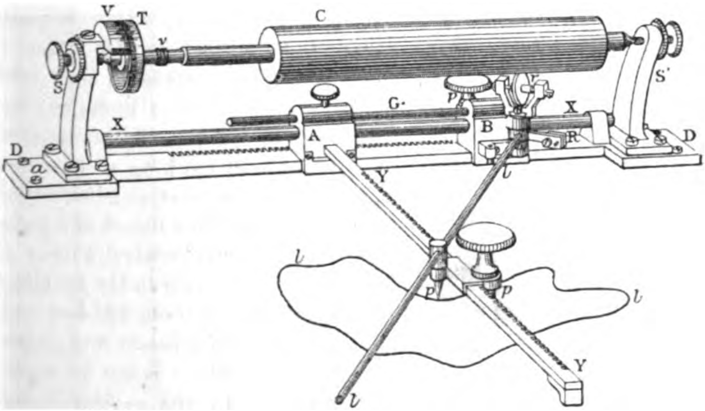
directly he had made a small area planimeter, he saw that a much simpler instrument could be devised by employing the wheels in a very small compass, and he should be happy to explain after the meeting to any one who might be interested the performance of the operation by the application of these small wheels. Mr. Mair, he believed, asked whether the readings of the instrument were accurate. It had not been tried so exhaustively as Amsler's instruments, and therefore he could not compare it with them; but he saw no reason why they should not expect the same accuracy from it as from those instruments in the non-slipping class concerning the accuracy of which they had already heard testimony. He greatly regretted that it had not been possible to prepare the engravings in time to be sent round with the Paper, or some points he had been anxious to have discussed would no doubt have been dealt with more fully by the various speakers. For instance, the points which Professor Hudson had referred to were actually treated in the Paper, and he ventured to think were, by means of diagrams, made perfectly clear. He would remark that with reference to the range of multiplier alluded to, although it was quite true that this was much greater in the case of the tangent form of integrator, in fact was infinitely great, yet for all practical purposes the sine form enabled quite sufficient range to be obtained, while the latter had the great advantage of allowing of the polar instead of the linear form of construction. He wished to say in conclusion that the point about which he felt extremely gratified was that none of the speakers, although many of them had had considerable experience concerning integrators, had taken any objection to the division of the subject he had made. When he began to write the Paper, his only object was to endeavour to classify and put in more concise form the details of the subject, but he found the utmost difficulty in doing so. He found out that the other classifications in use would not embrace all the instruments, and were very unsatisfactory; directly, however, the mode of treating the whole question, which he had employed in the Paper, occurred to him, the matter began to assume a clearer aspect, and he had found little trouble in grouping and explaining all known integrators by its means; and inasmuch as the classification had led him to certain modifications of his own instruments, he hoped that it would not be altogether without results to other workers on the subject.

Correspondence.

Mr. Abdank-Abakanowicz.

Mr. B. Abdank-Abakanowicz submitted a linear precision-planimeter of his construction (Fig. 58). This instrument was based on the employment of a cylinder C turning freely round its axis, and of a roller *r*, the plane of which could be inclined as wished in respect to the axis of the cylinder, and which could be moved along the generatrix of the cylinder. The displacement of any point of the cylinder was in proportion to the tangent of the angle that the plane of the roller formed with the axis of the cylinder. On a bar D D, fixed on the surface of a drawing, were mounted the pedestals S, S′ carrying between their points the cylinder C. The roller *r* was mounted on a carrier B, movable along the rod X X. Another carriage A supported a bar Y Y, perpendicular to X X. The two carriers were joined together by the rod *g*, and their distance could be varied to change the value of the constant. On the bar D D as well as on Y Y racks were cut, in which worked the pinions *p* and *p′*. The rod *l*, which made the plane of the roller deviate, was placed on the plane of *r* by means of regulating screws mounted on the arm R. In turning the two pinions *p* and *p′*, it was easy to follow exactly with the pointer P, the curve *b b* of which it was desired to find the superficies. There was then imparted to the triangle A B P a movement of translation, and at the same time its height A P was made to vary according to the ordinates of the given curve. The roller was always pressed by a spring against the surface of the cylinder. The number of turns of the cylinder was read on a

Fig. 58.

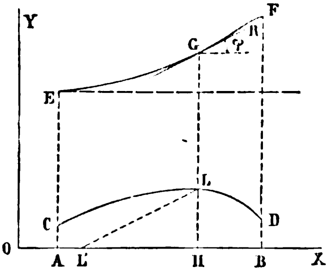


Mr. Abdank-Abakanowicz.

counter placed on an endless screw *v* (this counter was not shown on Fig. 58), and the fractions on the drum T supplied with a vernier V. The integrators of Mr. C. V. Boys were founded on the same principle, and he took the opportunity of stating that Mr. Boys had found this principle of integration independently of him, and that Mr. Boys had recognized the priority of his invention. In other respects the form of the apparatus of Mr. Boys differed from that he had constructed.

The other apparatus he had made on the same principle, for a special object he was now engaged in pursuing. He sought to make apparatus capable of tracing the integral curve, and it was to this special end he had directed his labours. This was briefly the problem: given the curve C L D (Fig. 59), of which the equation was $y = f(x)$, to trace mechanically another curve E G F, of which the equation should be $Y = \int f(x)\, dx + C$. The constant = A E. Since 1878 he had constructed machines to solve this problem, and he had brought them forward on various occasions.[1] It would occupy too long a time now to explain these instruments. They were made with the object of rendering service, particularly in the art of engineering, and in limits much more extensive than could be accomplished by planimeters. In reality the integral curve could be met with in almost all problems of statics. Those who were familiar with the elegant processes of graphic statics knew how important to the calculation of bridges, arches, statical moments and of inertia, was the outline traces by funicular curves. The machines that he had called briefly "Integraphs" traced these curves mechanically, and to obtain them it was sufficient to have the same data as for the ordinary methods of graphic statics. It would be possible to arrive at the same result with linear planimeters, but it would be necessary to operate by successive additions, whilst the machines would register at each moment the increment of the integral, tracing a curve on which could be made all the necessary geometric operations.

Fig. 59.



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[1] Comptes rendus de l'Académie des Sciences de Cracovie, 1880. Comptes rendus des Séances de l'Académie des Sciences (Paris). Tome 92 (1881), pp. 402, 515. Tome 94 (1882), p. 783.

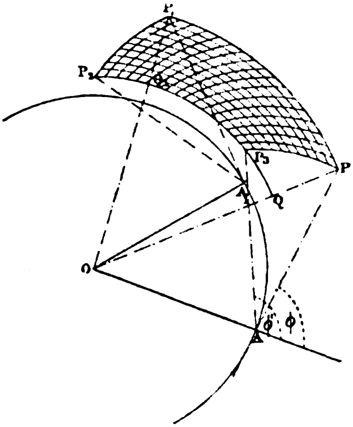
Major-General H. P. Babbage.

Major-General H. P. BABBAGE remarked that that which most interested him was the contrast between arithmetical calculating machines and these integrators. In the first there was absolute accuracy of result, and the same with all operators; and there were mechanical means for correcting, to a certain extent, slackness of the machinery. Friction too had to be avoided. In the other instruments nearly all this was reversed, and it would seem that with the multiplication of reliable calculating machines, all except the simplest planimeters would become obsolete.

Prof. A. G. Greenhill.

Professor A. G. GREENHILL said, suppose O to be the fixed centre, O A P the planimeter, A the joint containing the sphere (Fig. 60).

FIG. 60.



1. Fix the joint A, and move P to P_1 on the arc of a circle, centre O; then if O A turned through an angle θ, the dial at A would register an angle $M \theta \cos \phi$, if the angle between A P and O A produced was ϕ, and M was some constant.

2. Fix the joint O, and move P_1 to P_2 on the arc of a circle, centre A_1; the dial at A would not move.

3. Fix the joint A, and move A_1 back to A, and P_2 to P_3; then the dial at A would move back an angle $M \theta \cos \phi'$, if ϕ' was the angle between A P_3 and O A produced.

4. Fix the joint O, and move P_3 to P on the arc of a circle, centre A; the dial would not move.

In completing the circuit of the finite area P P_1 P_2 P_3, the dial would then have registered an angle $M \theta (\cos \phi - \cos \phi')$.

But the area P P_1 P_2 P_3 = area P P_1 Q_1 Q

$$= \tfrac{1}{2} \theta (\text{O P}^2 - \text{O Q}^2)$$

$$= \tfrac{1}{2} \theta (a^2 + 2 a b \cos \phi + b^2 - a^2 - 2 a b \cos \phi' - b^2)$$

$$= a b \theta (\cos \phi - \cos \phi^1), \text{ if O A} = a, \text{ A P} = b.$$

Then if M = $a b$, the dial would register the area P P_1 P_2 P_3.

Any irregular area must be supposed to be made up of infinitesimal elements formed in the same manner as P P_1 P_2 P_3.

Mr. Sang.

Mr. E. SANG observed that in the Transactions of the Royal Scottish Society of Arts[1] there was a description of a platometer, by Arthur Beverley, of Dunedin, New Zealand. In it the rubbing wheel was guided in a straight path. A very simple analysis showed that, because the tracer returns to its first position, the result was true, whatever might be the curve of this guide, so that Beverley's and Amsler-Laffon's were two cases of a general law. They were identical in principle; it was not likely that, in his out-of-the-way position, Beverley had known of the other.

Professor Shaw.

Professor SHAW remarked that he had already called attention to the fact that Mr. Abdank-Abakanowicz had anticipated Mr. Boys in the use of the non-slipping principle for integrators, but he was glad that the former gentleman had alluded to the tracing of an integral curve by instruments acting on this principle. This was a problem of considerable interest, and the Author might mention that he had, in a Paper before the Royal Society, called attention to a particular case of the integral curve. In this case if the section of any solid were taken on the plane of the paper, a curve, which he had called the curve of areas, might be drawn, the ordinates at any point of which represented the area of the cross-section of the solid at that point perpendicular to the plane of the paper. Such curves might no doubt be drawn by an adaptation of the instruments of Messrs. Abdank-Abakanowicz and Boys, and there seemed to be considerable scope for further investigation in that direction.

The Author was obliged to express his disagreement with the opinion of General Babbage, that all integrators except the simplest planimeters would become obsolete and give place to arithmetical calculating machines. Continuous and discontinuous calculating machines, as they had respectively been called, had entirely different kinds of operation to perform, and there was a wide field for the employment of both. All efforts to employ mere combinations of trains of wheelwork for such operations as were required in continuous integrators had hitherto entirely failed, and the Author did not see how it was possible to deal in this way with the continuously varying quantities which came into the problem. No doubt the mechanical difficulties were great, but that they were not insuperable was proved by the daily use of the disk, globe, and cylinder of Professor James Thomson in connection with tidal calculations and meteorological work, and, indeed, this of itself was sufficient refutation of General Babbage's view.

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[1] Vol. vii., p. 198.

5 May, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Member has been transferred to the class of

Members.

Malcolm M'Culloch Paterson.

The following Candidates have been admitted as

Students.

George Thomas Barlow.
Albert Brook.
Douglas Cator.
Jodoo Nauth Dutt.
Robert Francis.
Joseph Ball Hill.
Paul George Jacobs.
Frederick John Nickols.
Henry Vernon Remnant.
Edward Gower Stanley.
Peter Suarez.

The following Candidates were balloted for and duly elected as

Members.

John Argyle.
George David Bellamy.
Joseph Henry Brady.
Charles Dawney.
Charles Haynes Haswell.
Thomas David Little.
Leopold Dollfus de Méric.
Adrien Charles Mountain.
Richard Francis Trevithick.
Don Juan Whittemore.

Associate Members.

Sisley George Batten, Stud. Inst. C.E.
Arthur Horatio Brothers, Stud. Inst. C.E.
John Douglas.
William Henderson.
John Bramwell Hollom.
Albert James Humby, Stud. Inst. C.E.
James Langmuir.
Walter John Lomax.
James Michael Moore.
Henry Nelson.
Sir Reginald Louis Oakes, *Bart.*
Charles Beaufoy Pattrick.
Dashwood Poyntz Ricketts.
Henry Francis Smallman.
Percival Stevens.
Charles Baldwin Wake, Stud. Inst. C.E.
John Henry Whieldon.

Associates.

George Copus.
Louis John Crossley.

(*Paper No. 2044.*)

"The Signalling of the London and North-Western Railway."

By Arthur Moore Thompson, Assoc. M. Inst. C.E.

Railway signalling has become so important a branch of engineering, that the time will shortly arrive when the services of engineers, specially trained in this branch of the profession, will be required to carry it on.

That the work has not hitherto attracted the attention it deserves, is perhaps in a large measure due to the fact, that nearly all railway companies have placed it in the hands of contractors, and consequently, many who would have trained themselves for the work have been deterred by the absence of a demand for their services.

The system is not one calculated to effect that uniform arrangement which is so desirable; for although contractors have, as a rule, carried out their work satisfactorily, they have never had the advantage, which the Signal Engineer possesses, in the almost daily reports he receives of slight failures and other occurrences, which teach him where a faulty construction exists, or where an improvement in the arrangement of signals can be made. It may not, therefore, be unreasonable to predict that the more important railway companies will, ere long, manufacture their own signal-apparatus, and appoint engineers to superintend it; and the study of the subject will not be time ill-spent.

A brief history of signalling on railways will be found in Mr. R. C. Rapier's Paper, "The Fixed Signals of Railways," read before the Institution in 1874.[1] That Paper describes the successive steps by which signalling had arrived, from its first introduction, to its then comparative perfection. The object of the present Paper is to continue the history, by a brief description of the Signalling of the London and North-Western Railway, which the Author thinks may be taken as representing a good example of modern practice.

In 1873 the Directors of the London and North-Western Railway Company, in view of the large outlay which would be necessary in connection with the signalling and interlocking of extensive widening and other works then in course of construction, and also

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[1] Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 142.

PLATE 2.

OF T

TE KEY INTERLOCKING.

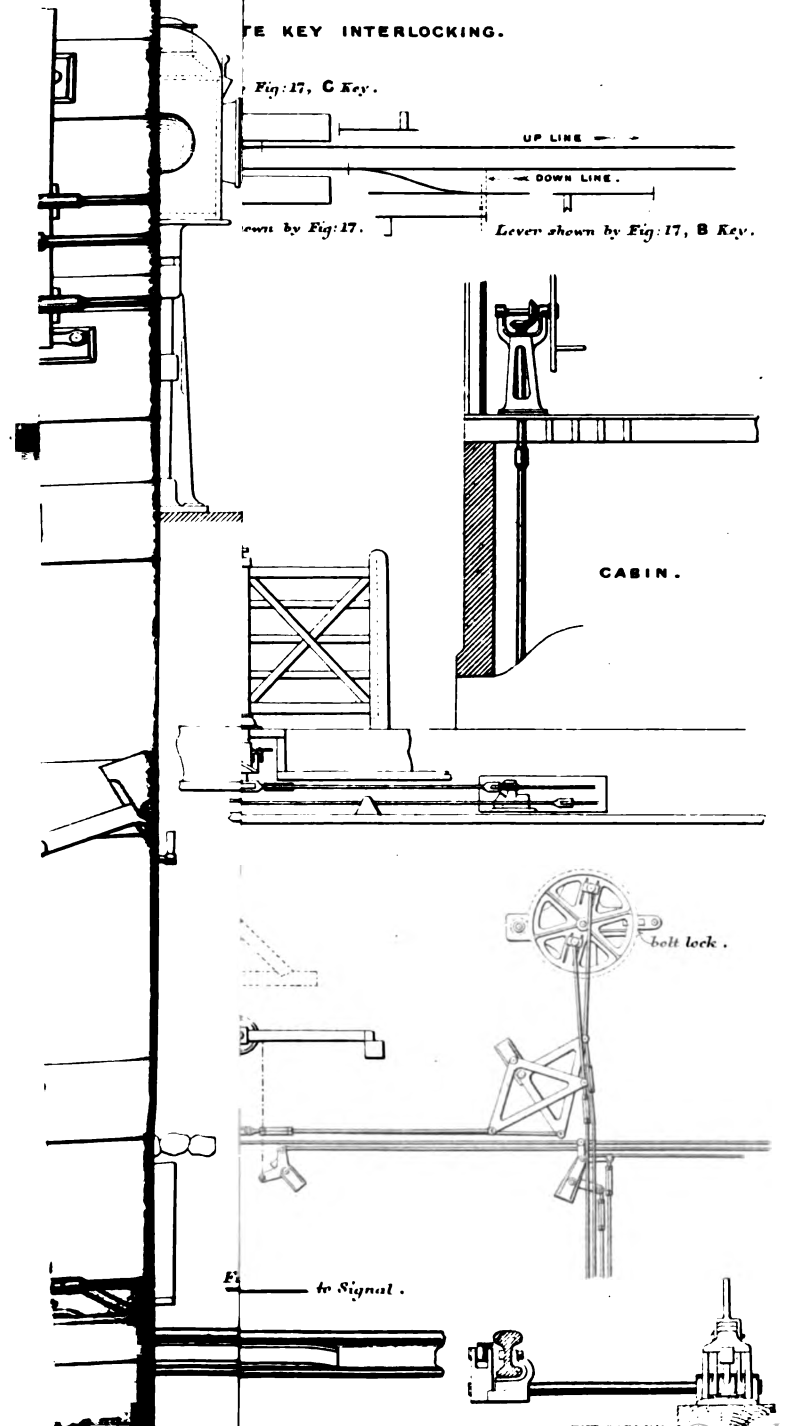


Fig: 17, C Key.
UP LINE
DOWN LINE.
own by Fig: 17.
Lever shown by Fig: 17, B Key.
CABIN.
bolt lock.
F
to Signal.

THOS KELL & SON LITH. 40 KING ST COVENT GARDEN

for the completion of the interlocking of the line with as little delay as possible, determined to place the work in the hands of an engineer who could devote the whole of his attention to the subject. They had for some time foreseen that the rapidly-growing importance of the work, which had already cost more than £1,000,000, would compel them, sooner or later, to relieve their District Engineers of the duty; and the work which was done by contract had led to the introduction of several types of locking-apparatus and signal-fittings, which necessarily caused delay and extra expense in carrying out alterations, or in effecting repairs.

Acting on the advice of their Chief Mechanical Engineer, Mr. F. W. Webb, M. Inst. C.E., the Directors instructed him to prepare shops and machinery at their works at Crewe for the manufacture of every appliance necessary to carry on the signalling of the line, and they instituted a Signal Department and appointed an engineer to superintend the work, and assist Mr. Webb.

In accordance with these instructions, Mr. Webb provided large fitting- and erecting-shops, carpenters' shops, and saw-mills, supplied with special machinery; and arrangements were made at the Company's steel works for rolling the Bessemer steel-point rod, locking bar, and other iron, and the stamping of the corrugated steel signal arms; while provision was made in the foundries and smithies for the large amount of cast- and wrought-iron required. Simultaneously with the fitting up of the shops, plans were prepared of the locking-apparatus, and other appliances requisite for the signalling of the line.

Locking-Apparatus.—It may be of some interest, before describing Mr. Webb's apparatus, briefly to trace the growth of the locking-apparatus.

The first arrangement for locking a point with a signal is that of Mr. Atkinson, which was provided at East Retford in 1852 to lock a signal with a pair of switches. In the following year Mr. Whitworth proposed a notched bar, in connection with the signal-wire, and crossing at right angles another notched bar working in connection with the points. It may seem a simple matter to group a number of these bars together, with the point- and signal-levers in a frame, and so produce a complete locking-apparatus, but fourteen years elapsed before the combination was proposed by Mr. Cariss in 1867.

The credit of having produced the first complete locking-apparatus is now generally given to Mr. Austin Chambers, who, in the latter part of 1859, provided frames at Kentish Town and Willesden

Junction. Shortly afterwards, Messrs. Stevens and Sons and Messrs. Saxby introduced improved apparatus. Between the years 1864 and 1866, schemes were proposed by Messrs. Anderson, Jeffreys, Bell, Skinner, Lea, Livesey and Edwards, and Owen, possessing, however, no features of great value. In 1866 Messrs. McKenzie, Clunes, and Holland produced the apparatus which, in an improved form, they are now manufacturing; the locking is of a strong but somewhat heavy type, and the parts numerous, but it is a good machine. An apparatus somewhat similar in principle is that of Mr. Brady, largely used by the South-Eastern Railway Company.

In 1867 Messrs. Saxby and Farmer introduced a spindle locking-apparatus, which was extensively used on the London and North-Western Railway; and many of them are still working well. In the same year Messrs. Easterbrook and Saxby brought out their catch-rod locking-apparatus, and between this date and the year 1870 schemes were proposed by Messrs. I'Anson, Kitchen, Easterbrook, Saxby, Buck, Baines, Baker, Rapier, Hannaford and Cochrane.

In 1870 Messrs. Stevens and Sons brought forward an improved form of apparatus, in which the locking is prompt and secure, and it is in every respect trustworthy. In the same year Mr. Smith introduced a pedal actuation apparatus, a well-designed and simple frame, which has done its work well.

In 1871 Mr. Saxby introduced a rocker catch-rod apparatus, which his firm manufactured for some years; and in 1872 Mr. Imray designed a catch-rod apparatus of an improved form, the best catch-rod frame at that time, which has been modified and adopted by the Midland Railway Company.

In 1873 Mr. Poole invented an apparatus, the locking being actuated by a side movement of the lever; and in the following year Mr. Saxby brought into use the improved form of rocker catch-rod apparatus; the locking is a modification of Messrs. Smith and Imray's, and it is in all respects a machine to be relied upon.

In the same year Mr. Webb introduced a catch-rod locking-apparatus, embodying several details of value, together with a simple form for outlying sidings, which is largely used by the London and North-Western Railway Company (Plate 2, Fig. 1); and in the following year he improved the apparatus, the motion of the catch-rod being communicated to the locking-bar through a cam-slot formed in the head of the vertical locking-bar (Fig. 2).

In 1876 Mr. Webb proposed a locking-frame, the locking being actuated by the lifting of the lever, the catch-rod acting as a fulcrum; and in the same year he introduced the apparatus now in general use on the London and North-Western Railway, which the Author considers, both as regards design and workmanship, to be unrivalled (Fig. 3). The amount of wear and tear in a frame working a busy junction is so great, that, if badly constructed, it is sure to be frequently out of order, and at a time when perhaps it is almost impossible, on account of the traffic, to effect the necessary repairs. Mr. Webb, therefore, kept prominently in view the advantage of having a strong machine, of the simplest possible construction, few parts and these interchangeable, large wearing surfaces, and the whole easily accessible for cleaning and repairs; and he decided that it would be more economical in the end to fit it up with as much care as is bestowed on a locomotive engine, relying on special machinery to cheapen production, rather than, as it were, to throw rough castings together without fitting, as had been too frequently the case. Somewhat hampered at the start by the claims of inventors, an apparatus was produced which embodied all the characteristics constituting a good machine.

Instead of casting the quadrant-plate in one piece, to contain from ten to fifteen levers, as is the usual practice, each lever is centered on a casting (A, Fig. 3), which forms its own quadrant; and these levers and quadrants are, so to speak, threaded together to form an apparatus of any desired size.

A special rose-cutting machine is employed in facing the quadrants, and the facings C, D, E, F, G, H, I, are cut at one operation, which ensures all quadrants being exactly alike, and thus a lever can be renewed, or an additional lever added to a frame, without any fitting being necessary on the spot.

The locking-frame is of the horizontal and vertical bar type, but much more carefully constructed than usual. The horizontal bars (J, Fig. 3) are of Bessemer steel, rolled to a shallow channel section (Fig. 4); the locking-studs are squared to fit the channel, and are then secured by riveting. The vertical notched bars (K, Fig. 3) are also of steel, the notches being punched out cold. Each vertical bar is guided by a channel the length of itself, and one wall of this channel is made deeper than the other, and notches are cast in it to act as guides for the horizontal bars, the notches being faced by a special drifting-machine at the rate of thirty-five notches per hour.

The locking is known as "lever-locking," to distinguish it from "catch-rod-locking," and the motion of the lever is communicated to the vertical notched bars by a double hook-shaped lever (L, Fig. 3), centered on the lever, which hooks over a projection (M, Fig. 3), cast on the lever-quadrant casting. Upon the lever being moved about $\frac{1}{32}$ inch, the hook-lever is tilted up, communicating sufficient motion to the locking-bars to effect all necessary locking; and it is further tilted when the lever is within $\frac{1}{32}$ inch of its pulled-over position, communicating additional motion to the locking-bar to effect the necessary unlocking.

Owing to the position of the centre upon which the hook-lever turns, any strain put on a locked lever is taken principally by the main framing, and the locking, which is of a light design, is thus saved from undue strain. If the apparatus be large, and the locking-bars numerous, the vertical notched bars are divided in the middle by a short compensating lever, and being thus counter-weighted, any length of bar may be used; a frame in course of construction for Rugby has bars 18 feet deep. A detail, highly appreciated by the signalmen working these frames, is the loop handle (N, Fig. 3) which Mr. Webb has substituted for the spring catch-handle usually provided.

Of the twenty-six thousand five hundred levers on the London and North-Western Railway, about one-half are of Mr. Webb's pattern. Their working has been everything that can be desired; and although many of the frames are at very busy junctions, notably Crewe, with one hundred and forty-four levers, and Springs Branch, with eighty levers—in which latter cabin nine thousand nine hundred and sixty-five levers are pulled over and put back in twenty-four hours—the cost of maintenance has been trifling.

The largest frame of Mr. Webb's pattern is that provided at Crewe, where six lines of railway meet at a common junction north of the platforms. Previous to the erection of this frame the junction was controlled from two signal cabins, and some doubt was raised as to the wisdom of concentrating so much work in one cabin. A single cabin containing one hundred and forty-four levers was, however, provided, with the result that the junction has been worked more economically and with increased safety, misunderstandings likely to arise out of a joint control being avoided.

An apparatus in course of construction for working the south junction at Rugby will contain one hundred and eighty levers, eighty-four horizontal locking-bars each 83 feet long, and one hundred and eighty vertical bars each 18 feet deep. The cabin will be 96 feet 6 inches long by 12 feet wide, and 23 feet high.

Signal Cabins.—These do not need special notice. The upper portion is, as usual, constructed of wood, and the lower portion, as a rule, of brick. All the timber-work is cut to template, and the length of the cabin is determined by the number of sashes, which are of a standard size.

The following list gives the sizes of the cabins, and the number of levers they are constructed to contain :—

	Feet.	Ins.		Feet.		Levers.		Feet.	Ins.		Feet.		Levers.
A . .	6	0	by	6	to hold	5	K . .	32	3½	by	12	to hold	50
B . .	9	0	,,	9	,,	10	L . .	35	0	,,	12	,,	55
C . .	13	5½	,,	12	,,	15	M . .	38	7½	,,	12	,,	60
D . .	16	2½	,,	12	,,	20	N . .	44	0	,,	12	,,	70
E . .	18	9	,,	12	,,	25	O . .	48	9	,,	12	,,	80
F . .	21	6	,,	12	,,	30	P . .	54	1½	,,	12	,,	90
G . .	24	1½	,,	12	,,	35	R . .	65	6	,,	12	,,	112
H . .	26	6	,,	12	,,	40	S . .	80	4½	,,	12	,,	144
J . .	29	8	,,	12	,,	45	T . .	96	6	,,	12	,,	180

All cabins holding more than fifty levers are warmed with hot water, and this is found to greatly improve the working of the long locking-bars, the uniform temperature counteracting the expansion and contraction which takes place in a large cabin heated by an ordinary firegrate or stove. When hot-water heating is adopted, gas-stoves are, in addition, supplied for the signalmen to warm their food. The number of signal cabins is one thousand three hundred and forty-four.

Signals.—The semaphore type of signal, introduced on the Croydon Railway in the early part of the year 1842, by Mr., now Sir, Charles Hutton Gregory, K.C.M.G., Past-President Inst. C.E., has since been adopted on all British railways. It is rather singular that this simple form of signal, which was in use for signalling purposes as far back as the seventeenth century, should only have been generally adopted after almost every other conceivable form had been introduced. Revolving disk-signals of various forms were the most common, and there are many still in existence, a large number of the distant signals on the Midland Railway still being of the disk form, but semaphores are being rapidly substituted to comply with the regulations of the Railway Clearing House.

That signals on all railways should be uniform in type is most desirable, and it is to be hoped that the time may come when railway companies will not only adopt a uniform type, but will pay greater attention to the grouping and general arrangement. On an ordinary double line of railway there is little difficulty in arranging signals so as to be easily read by the dullest driver; but now that four lines of railway are becoming common, and large stations are erected with four or more separate, and perhaps parallel, lines, meeting at a complicated junction, the ingenuity of the Signal Engineer is exercised to the utmost, to present to the view of drivers an arrangement of signals which cannot easily be misread. The too common system of grouping a large number of signal-arms on one pole applying to several approaching roads, or providing prominent signals for subordinate lines or shunting operations, dotted up and down an important junction, regardless of the appearance they present to drivers, should not be tolerated.

No doubt a great deal of this bad signalling is due to the fact that the plan of the permanent-way is agreed to, and the roads perhaps laid down, before the Signal Engineer has been consulted; and consequently he has to content himself with such sites, in many cases quite unsuitable, as are available for signals. To avoid this, the plan of the permanent-way and the plan of the signals should invariably be schemed together, so that not only may suitable sites be left for the signals, but an opportunity afforded the Signal Engineer to suggest such alterations in the roads as may be found necessary to secure a satisfactory arrangement.

The signal adopted by Mr. Webb (Fig. 5) is of the ordinary semaphore type, the poles being of pitch-pine timber, varying in size from 9 inches by 9 inches to 15 inches by 15 inches at the bottom, according to the height of the post, to 6 inches by 6 inches at the top, upon which is placed a galvanized iron cap. The bottom part of the post, for about 7 feet, is left the full size of the timber from which it is cut, and thus, at the "wind and water," or ground level, where the process of decay is most rapid, 18 inches or more timber is left, which, after being charred, is well coated with gas-tar. The signal-arm is formed of a thin steel plate, stiffened by two corrugations running lengthways of the arm; this is riveted to a galvanized cast-iron centre, upon which is fixed an adjustable frame for the spectacle-glasses, made sufficiently heavy to counterbalance any accumulation of snow on the arm, and to keep it in its danger position should any of the fittings fail. The arm works on a spindle squared to receive it at one end, and the back-light lever at the other, and the spindle turns in a casting fastened to the post by four $\frac{5}{8}$-inch bolts, which also serve to secure the lamp-bracket placed at the back of the arm; this is of sufficient width to form a stop for the arm when in its danger position.

Bracket signals are fitted in the same way as single posts, and the only detail that need be mentioned is the light wrought-iron bracket (O, Fig. 5), which has been substituted for the heavy cast-iron bracket usually employed, as the latter adds an unnecessary weight to the post, holds more wind, and is more troublesome to erect.

For siding signals, a simple form of ground disk-signal is employed (Fig. 6).

The London and North-Western, and most other railway companies, still retain the white light as an all-right signal for intermediate block cabins and unimportant stations, and the green light as a caution signal for junctions and important stations.

The Great Northern Railway Company has, however, abandoned this practice; they treat the white light as a danger signal, as well as the red light, and employ a light-green light as the all-right signal. A little more than one-half the signals on the London and North-Western Railway exhibit red and white lights, and the rest red and green.

The Great Northern Company has also adopted a signal-arm centered midway in its length, as shown by Fig. 7, so that any accumulation of snow on one end is counterbalanced by the accumulation on the other end—a somewhat unnecessary refinement, however, the object being equally well attained by a counterweight, without departing from the form of semaphore generally adopted.

The number of signals now in use on the London and North-Western Railway is as follows:—7,785 semaphore posts, with 11,542 arms; 1,985 siding ground disk-signals; 21 point-indicators.

To ensure a uniform arrangement of signals, instructions have been issued to the men as given in Appendix I.

Signal Slot.—This is an apparatus invented in 1862 by Mr. Gill, an assistant engineer of the London and North-Western Railway Company, who fixed the first one made to a signal at Shap, near Carlisle. The apparatus is employed when it is necessary for a signal to be jointly controlled by two or more signalmen. At one time it was used for controlling junction-, home-, and starting-signals to act as distant-signals for a cabin in advance; but this practice has been abandoned, as it led to drivers being called past such signals when at danger, to perform shunting operations, &c.; and not only were drivers thus educated to pass signals at danger, but mishaps were continually resulting from hand signals being misread, or the road not correctly made, due to the fixed signal, which alone controls the locking, not being used. Lower distant arms have been substituted, and a large expenditure has been involved by the change. These distant arms are fixed 7 feet below the home arm, and slotted with the top arm, so that the distant arm cannot be off when the home arm is at danger—an obvious and very necessary precaution.

When, however, signal cabins are so close together that the distant-, home-, and starting-signals are common to both, there is no objection to the control by a slot, and this arrangement is adopted when necessary, although some companies have abandoned it. The form of slot adopted by the London and North-Western Railway Company is shown by Fig. 8. In 1880 the Author introduced a wheel-slot (Fig. 9), an apparatus which enables any number of cabins to control a signal by a single wire, which has effected a saving of some thousands of pounds in first cost.

Adjusting Apparatus.—Difficulty has always been experienced in counteracting the expansion and contraction of long lengths of wire used for the working of distant signals. Many schemes have been proposed, but they all have proved complicated and unsatisfactory. The best position for a compensator is at the signal-post, but a satisfactory arrangement in this position has not yet been found, and there are difficulties connected with it which are practically insurmountable.

Apparatus fixed midway between the signal and the lever works fairly well, but, with one exception, all kinds have the grave fault, that should the wire between the apparatus and the lever become slack, either by the wire breaking or a joint drawing, there is danger of the signal being pulled off. The only scheme which gets over this difficulty is the recent one of Mr. Johnson, who employs glycerine in tubes. Grip apparatus, fixed on the lever in the cabin, is the least complicated, and most trustworthy. When self-adjusting apparatus is not provided chains should be fixed as near the cabin as possible, or means afforded by which the signalman can adjust the wires without leaving the cabin.

Point-Rods.—The most common form of rod for working points is ordinary 1-inch gas-piping, the joint at first being formed by the usual screw-ferule. The screw-threads of the ferule, however, corroded and stripped; and the joint was consequently superseded by one through which a spigot was inserted, and secured by two riveted pins, in addition to the ferule. This joint was in use for a considerable time, but many failures having occurred, cotters were finally substituted in lieu of the pins; and in this form it has been adopted by all the principal railway companies who employ gas-piping, with the exception of the North-Eastern Railway. This company still uses a ferule only, the ends of the piping, however, being made solid, and the ferule somewhat longer. For some years the Midland Railway Company used solid round rod-connections, laid down in long lengths, and joined by means of a wrought-iron hexagon adjusting screw, but steel piping has lately been substituted.

In view of the large number of facing-points, in many cases worked at a distance of 150 yards from the signal cabin, and over which trains travel with undiminished speed, a strong and thoroughly trustworthy connection is of the utmost importance. Mr. Webb decided to adopt a steel rod of a channel section (Fig. 10), which is not only stronger than gas-piping, but rods of this form weakened by corrosion are readily detected and removed. The use of gas-piping was abandoned, as it is frequently manufactured of poor iron, and corrosion goes on rapidly in the interior of the pipe, so that it is almost impossible to detect when a rod has become insecure. The steel channel rod is rolled at the Company's works at Crewe, and it is sawn off in lengths of 18 feet. Before leaving the works it is heated and dipped in oil, and when laid down permanently it is coated with red lead. The joint is formed by a fish-plate of a section to fit into the channel, and secured by six ½-inch bolts. The fish-plates are rolled and sawn off to the exact length, and the six holes are then drilled at one operation by a special machine, the corresponding holes in the rod being also punched at one operation. The rod runs on small rollers, cast to fit the channel, and these rollers are carried by cast-iron frames. The rod has been in use on the London and North-Western Railway for nearly ten years, during which time there has not been a single failure. It is now being adopted by the Lancashire and Yorkshire Railway Company.

Point-rod Compensators.—Of the various compensators, the London and North-Western Railway Company retains the old form of lever fixed vertically, as being simple and thoroughly efficient.

Point-rod Adjusting-nuts.—Slight mishaps having occurred, due to the breakage of the cast-iron adjusting-nut, Mr. Webb adopted a steel nut of hexagonal form (Fig. 11). The nuts are rolled at Crewe, and sawn off to the right length, and then drilled and tapped. At a distance of 1½ inch from each end a detector hole is provided, so that the signal chargeman in going his rounds may ascertain if the screw has been driven too far by the platelayers in adjusting the points. This is a very necessary precaution.

Goose Necks.—Several patterns of this so-called fastening between the point-rod and the switch-tongue are in use, and the London and North-Western Railway Company has adopted the joint (Fig. 12), it having proved thoroughly trustworthy.

Facing-Point Locks.—After some serious accidents had occurred at facing-points, due to the points not closing properly, or the signalman moving the lever when a train was travelling over the points, the necessity for additional security became manifest, and the simple and now universally adopted locking-bar introduced by Messrs. Livesey, Edwards and Jeffreys, in the year 1867, and which was afterwards improved by the addition of a bolt, &c., by Mr. Saxby, supplied the want.

The apparatus (Fig. 13) consists of a piece of T- or angle-iron, somewhat longer than the widest wheel-base of the carriages running on the railway, fixed on the inside or the outside of the rail, in advance of the facing-points, and carried by short levers. The bar in its normal position lies just below the flange of the wheel, and, when in movement, rises to the level of the rail, and again drops to a position below the wheel flange. In connection with the bar is a plunger, which enters a hole in the point stretcher-rod, and thus the points are firmly secured in position. The apparatus is worked as follows:—When the signalman has moved the points to the road on which a train is to travel, he pulls over the lever which actuates the bar—thus securing the points and releasing the signal. The signal-lever is then pulled over, and the facing-point and locking-bar levers become locked. But should the signalman put the signal back when the train has passed it, and attempt to move the locking-bar lever when the train is running over the points, it is locked by the flange of the wheels, and thus the train secures the locking whilst passing over the points, and the danger of a train running over facing-points at a high speed is, by this invention, reduced to a minimum. Shortly after the introduction of this apparatus a slight defect was made apparent by several accidents, due to the breakage of the rod working the points. This enabled a signalman to lock the points and lower the signal for the main line, when the points were unmoved and standing open, say, for a loop- or bay-line. To obviate this, Mr. Rapier proposed a bolt of two different sections, one section locking only for the loop-line, the other for the main line. This was followed by a scheme by Mr. Saxby for an improved method of working the bolt, which was again succeeded by a duplex bolt proposed by Mr. Webb. All these schemes, however, added complication; they have not been adopted, and attention has been confined to improving the connections. As an additional precaution, however, it is desirable, at important facing-points, to provide a detector-lock, in connection with the main line signals. The lock adopted for this purpose by the London and North-Western

Railway Company is one designed by the Author (Fig. 13*a*). The chief novelty is the provision of a separate rod for each switch-tongue, thus ensuring that should either tongue be out of position the fault is at once detected, which would not be the case if one rod only were provided.

To save the additional lever required in connection with the locking-bar and bolt, several schemes have been proposed, and on some railways largely adopted, for working both the points and locking-bar and bolt by one lever. But the arrangement is one which should not be recommended, as the stroke of the lever—short enough in the ordinary apparatus—is reduced by two-thirds; one-third being required to withdraw the bolt, one-third to work the points, and one-third to bolt the points again; consequently, if the movement of the point is obstructed by a stone, and the connection not very strong, there is a chance that the signalman may pull the lever over by buckling the rod, as he does not feel the obstruction until the lever has made nearly two-thirds of its stroke.

Several forms of locking-bar apparatus have been introduced by Messrs. Bell, Brady, Buck, Edwards, Harrison, Luke, Stevens, Webb, and the Midland Railway Company; but the London and North-Western has adopted the Livesey bar as improved by Mr. Saxby.

At all facing-points, a strong gauge-tie is provided, and to this the plunger-casting is bolted. The apparatus in the 4-feet way should be carefully boxed in, and the lids which open to enable the cranks, &c., to be oiled and cleaned, should be hinged, so as to prevent a chargeman leaving the lid on the rail.

There are 1,629 facing-points on the London and North-Western Railway; all, with the exception of a few on unimportant branch lines which are padlocked, are either fitted with locks and bars, or secured by a train-staff lock.

Locking-Bars.—Frequent mishaps result during shunting operations, from the signalman moving the points before the train is clear of the line. It is a good plan to provide points, which are a long distance from the signal cabin, with a locking-bar to work in connection with them, and a considerable number of the points on the London and North-Western Railway are so fitted; but in busy station-yards, where there is a great deal of shunting, bars are not to be recommended, as they are often broken down by vehicles striking their end whilst being pulled over.

Detector-Bars.—It frequently happens that a signal cabin is so placed, that the signalman cannot clearly see whether vehicles standing, say, in a bay-line, are clear of a platform-line from which he wishes to signal a train, or whether a bay-line is clear, into which a train is about to be signalled. To meet the difficulty Messrs. Park and Pryce introduced their "train protection bar" (Plate 2, Fig. 14, and Plate 3). This is a light locking-bar actuated by the same wire that works the signal, and so arranged that, as the signal-lever is pulled over, the bar is lifted to the level of the rail, or nearly so, and thus the signalman is prevented from pulling off a signal should a vehicle stand on the bar.

To prevent the bar being left at the level of the rail whilst the signal remains off, the lever actuating the bar is provided with a pawl, which engages with a quadrant-piece attached to the shaft working the bar; as the signal is pulled off, the pawl carries the quadrant-piece round with it, until the bar is nearly at the level of the rail, when an incline on the bracket raises the pawl and allows the bar to drop again to its normal position; the signal being put to danger again, the pawl re-engages with the quadrant-piece, and the bar is again in a position to be raised and act with the signal.

The bar is useful at stations where it is necessary to have an advanced starting-signal in a tunnel; four or five bars may be laid down between the tunnel mouth and the starting signal; but in this case it is better to work the bars by a separate lever and a rod connection—the lever being so interlocked that it must precede all levers adjusting signals for trains to enter the tunnel. Bars are being provided for this purpose at New Street, Birmingham, and other places.

These bars are also suitable as "duplicate bars" when provided in lieu of repeater signals at junctions where the outlying signals are more than 200 yards from some of the facing-points. The Author has arranged the bars for this purpose with as many pawls as there are facing-point locks in advance, and worked in connection so that the locks cannot be withdrawn so long as a train is travelling over the detector-bar; thus the objectionable practice of placing repeater signals in the middle of a large junction can in most cases be avoided.

Train-Staff Locks.—For locking the points on single lines, a cheap and simple plan is to provide a lock at the points, and secure the key to the train staff. Any lock of a strong pattern will do, but it must be impossible, when the key is inserted, and the points unlocked and moved, to withdraw the key until the points are put back and locked again. This arrangement dispenses with all signals, and it has been adopted to a large extent on the

London and North-Western Railway, the lock employed being shown by Fig. 15.

The train-staff system of working single lines of railway will ere long, no doubt, be superseded by the more convenient system, recently introduced, of "electro tablets," when some arrangement will have to be schemed to take the place of the staff-key.

Locks for Outlying Sidings.—A simple and inexpensive arrangement for locking a siding, too far removed from the signal-cabin to be secured by bolt-lock, was introduced by Mr. Annett in 1875 (Fig. 16). A strong lock, of any ordinary pattern, is fitted to the siding points, and a similar lock to the locking apparatus in the signal-cabin, one key common to the two locks being provided. The lock in the signal-cabin is so arranged that the key cannot be withdrawn until a bolt is shot, which locks all points and signals for the road with which the siding connects; the key can then be carried to the siding, and the points unlocked. The points being pulled over, the key becomes locked, and cannot be withdrawn again until the points are put back, when the key can be turned to lock the points and withdrawn.

At the suggestion of the Author, this simple arrangement has been employed on the London and North-Western Railway for cheaply interlocking unimportant roadside stations, and it has proved to be very safe and satisfactory. Take, for example, a roadside station with a level crossing, a cross-over road and sidings connecting with the up and down lines, the staff consisting of the station-master only, who has to attend to everything, including the block instruments. Interlocked in the usual way, a signal-cabin and locking-apparatus would be provided, and costly connections laid down to work the siding-points, which are perhaps only used once or twice during the day, at a cost of £300 or £400; and, in addition, a signalman is necessary, at a further cost of £60 per annum. In carrying out the interlocking of such a station by means of keys, a small ground frame would be provided, either in the booking-office, where the block instruments are placed, or on the platform close to the door of the booking-office, and it would contain levers for working the signals only. Three locks, with keys, would be attached to this frame, and in connection with the locks three bars would be provided, the movement of which, by the withdrawal of a key, would effect the necessary locking. The action is as follows (Fig. 17):—Say a train arrives on the up road, and has a wagon to pick up from the up siding. The station-master places the up signals at danger, and withdraws the key of the up siding, which may be called Key A; the withdrawal of the key locks the up signals, and, if necessary, the cross-over road and level-crossing gates. Or, should the down siding have to be used, Key B would be taken, locking all down signals. If the level-crossing or cross-over road is to be used, Key C is withdrawn, locking both up and down signals. Thus a small roadside station may be securely interlocked, and the appointment of additional staff avoided, at a trifling expenditure, and the arrangement would undoubtedly have been welcomed by companies who can ill afford the serious cost involved by the ordinary mode of interlocking. But the Board of Trade, whilst acknowledging the complete efficiency of the arrangement, raise an objection on the plea that it does not accord with the regulation—made, by the way, when interlocking was in its infancy—that the levers working points shall be grouped with the levers working signals on a raised platform, a plea which, it is to be hoped, will be withdrawn after further consideration.

Electric Locks.—For an outlying siding too far removed from the cabin to be bolt-locked, and when too much time would be occupied in carrying an Annett's key between the cabin and the siding, several arrangements of electric locking have been devised, the London and North-Western employing one designed by its telegraph engineer, Mr. Fletcher, which satisfactorily meets the requirement.

Gate Locks.—When level-crossing gates are worked from a signal-cabin, the gearing in the signal-cabin is usually locked, but there are many gates which are locked only, and the most common system is to provide a plunger-bolt at the head of the gate, and a feeler bolt and quadrant at the heel.

A neater arrangement was introduced by Mr. Black in 1877 (Fig. 18); he fixes a special form of lock on the gate-post, controlled by a rod from the signal-cabin, a bolt in the form of a key being attached to the gate. To open the gate it is necessary, first of all, to withdraw the rod worked from the cabin, and so lock all necessary signals; the key-bolt attached to the gate can then be turned and withdrawn, and the gate opened. The withdrawal of the key back-locks the rod from the cabin, and thus the signals are kept locked at danger until the gate is closed, and the key-bolt inserted and turned again.

A simple arrangement is shown by Fig. 19. In this case a strong lock, with a long bolt, is attached to the gate, and a similar lock attached to the locking-frame in the signal-cabin, one key common to both being provided. To unlock the gate, the key is withdrawn from the lock in the signal-cabin, its withdrawal locking the necessary signals. The key is then carried to the gate, and the long bolt unlocked, raised, and the gate opened; the raising of the bolt locks the key, which cannot be withdrawn again to unlock the signal until the gate is closed and the long bolt replaced.

Level-Crossing Gates.—The wear and tear of the apparatus working a busy crossing, and the strain on the connections, are so great, especially when the gates are large, that it is very important to adopt connections and gearing of a strong and substantial design, as otherwise the gates will be continually out of order, the repairs perhaps involving the pavement of a busy roadway being taken up. The pattern adopted by the London and North-Western Railway (Fig. 20) is of a very substantial design. Steel rods of a channel section are used for the connections, and the gates are worked by heavy sectors rack-geared with the rods. Many gates have been put up, and their working is everything that can be desired, the cost of maintenance being trifling compared with gates worked by chain gearing.

Interlocking of Block Instruments.—To prevent a signalman from signalling a train into a forward section unannounced, or before "line clear" for a preceding train has been received, or giving "line clear" for the section in the rear before a train previously accepted has arrived, apparatus has been proposed by Messrs. Preece, Sykes, Hodgson, Siemens, Tyer, Langdon and others, for electrically controlling the starting signal for a cabin in the rear, and mechanically or electrically locking the block instruments with the out-door signals and points; the proposal undoubtedly adds complication, but it has been adopted with advantage on some busy Metropolitan lines. On trunk lines, where the block stations are far apart, and the trains are run at greater intervals of time, the necessity for such apparatus is hardly felt; but as traffic increases, and block stations become more numerous, it will no doubt in certain cases be advisable to adopt some such additional means of security.

A description has now been briefly given of the principal apparatus employed by Mr. Webb in the Signalling of the London and North-Western Railway. Details of minor importance have been omitted, a description of which would have been of interest had space permitted.

The number of indoor men employed at Crewe in the manufacture of signalwork is two hundred and thirty-two.

New works are carried out by an out-door gang, consisting of three inspectors, ten foremen, and from ninety to one hundred and fifty men, the number varying with the amount of work in hand.

For the maintenance of the signalwork of the line (1,783¾ miles) district store-sheds are provided at Watford, Rugby, Stafford, Crewe, Abergavenny, Craven Arms, Warrington, Tyldesley, Heaton Norris, Lancaster, and Llandudno Junction, the maintenance staff consisting of eleven district inspectors, eighteen sub-inspectors and foremen, sixty-three chargemen, and four hundred and twenty men. The cost of maintenance per annum is £38,500, giving an average cost of £1 9*s*. per lever.

In addition to the company's book of rules, each man employed on the out-door work of the department is supplied with a book containing the instructions, given in Appendix II., which are strictly enforced to ensure the safe conduct of the work.

The Paper is accompanied by numerous illustrations, from which Plate 2 and the figure in the text have been engraved.

[APPENDIXES.

APPENDIX I.

LONDON AND NORTH-WESTERN RAILWAY.

(Circular No. 1706.)

SIGHTING SIGNALS.

Instructions to Inspectors.

To secure uniformity in the arrangement of signals the following rules must, as far as possible, be observed.

The arrangement of the signals shown on the plan prepared by the Signal Superintendent should be adhered to, and sighted for as nearly as possible as shown on the plan—any modified arrangement suggested by the Inspectors on the ground being sighted for and added to the plan as a rider.

Distant Signals.—These signals should be fixed at an uniform distance of 1,000 yards from the home signal, unless the gradient is a rising one, in which case a distance of 800 yards will be sufficient. In special cases a distant signal may be fixed at a distance of 1,200 yards from the home signal, provided the Signal Inspector agrees that he can obtain a sufficiently direct route for the wire connections to ensure the signal working freely. On no account must a signal be fixed at a greater distance than 1200 yards from the cabin.

Home Signals.—These signals should be seen by a driver from the distant signal, and must be fixed as close to the cabin as possible, so that a driver whose engine is standing at the signal may be verbally communicated with by the signalman.

Junction Signals.—The same rule applies to the sighting of these signals as for *home* signals. They must be fixed near the facing points to which they apply, and in no case must they be at a greater distance than 200 yards from the facing points, unless repeater signals or duplicate locking bars are provided.

Junction signals for protecting a junction in the trailing direction should be fixed so far from the fouling point as to afford a margin for a driver should he accidentally draw past the signal.

Junction signals must not in any case be placed on the same post one above the other, but a separate post must be provided for each signal.

This rule need not apply to bay starting or other subordinate signals; in these cases the signals may be placed on a single post, one signal above the other. The top signal must then apply to the road leading off to the left-hand, the second signal to the next left-hand road, and so on.

Platform Starting-Signals.—These must be sighted at a height of about 15 feet above rail level, and it will be sufficient if they be seen by a driver the length of the platform.

This rule will not apply if the starting signal post carries the distant signal of a cabin in advance, or if the starting signal acts as a home signal for a cabin in advance; in these cases the signals must be sighted as distant and home signals respectively.

Advanced Starting-Signals.—These signals may be sighted of an uniform height with platform starting-signals, of 15 feet above the rail level; they should be seen by a driver from the platform starting-signal, and must not be at a greater distance from the cabin than 350 yards. If an engine or other obstruction standing at the advanced starting-signal cannot be clearly seen by the signalman, the signal must not be provided, and it will then be necessary for the sidings in advance of the platform starting signal to be worked in the block.

Bay starting and other subordinate signals should be of an uniform height of 15 feet above rail level, have short arms, and *be provided with purple lights.*

A distant signal for a cabin in advance must never overlap a home or starting signal for a cabin in the rear, but must be fixed on the same post 7 feet below the home or starting signal, and be controlled by the home or starting signal, to prevent the distant arm being off when the home or starting arm is at danger. When a distant signal is placed below a home or starting signal, no other signal must be placed on the same post, excepting "fog" or "calling-on" arms.

When the distant signals for a junction have to be combined with the home or starting signals for a cabin in the rear, then the starting signal post must be nearest the line with the distant arm for the right-hand junction placed under it, and the distant signal for the left-hand junction must be carried by a separate post to the left of the home or starting post. Both distant arms must be controlled by the home or starting signal. This rule will not apply if the junction to the right is a goods loop or other subordinate line; in this case, the distant signal must be carried on a separate post to the right of the home or starting post.

Lamps must never be placed nearer together than 7 feet, with the exception of bay starting or other subordinate signals, for which the lamps may be fixed closer together.

Back Lights, which cannot be seen by the signalman working the signals, must be dispensed with unless they can be seen from a station platform; in this case they may be retained if it is considered desirable.

Signals elevated more than 45 feet above rail level must have a lower or fog arm, worked in connection with the top arm at an elevation of 15 feet above rail level, but a single lamp only is necessary, to be opposite the bottom arm when practicable.

Signal Cabins should be so placed that the signalman can see all points and signals from the levers working them, especially facing points, which must be in all cases clearly seen.

Electric Repeaters must be avoided, as far as possible, even at the expense of higher signals. If a repeater cannot be avoided, then the signals should be only sighted at such an elevation as to give a driver a good sight.

All Signals should be fixed on the left-hand side of, and as near as possible to, the road to which they apply.

A signal cabin or signal placed on a passenger platform must not be at a less distance than 6 feet from the nosing of the platform, and a cabin or signal must not be erected at a less distance than 4 feet 6 inches from a passenger line.

The Inspectors must each consider the general arrangement of the signalling. It will be the special duty of the *Traffic Inspector* to see that the signal cabin is suitably placed, and that the signals are seen by the Signalman. It will be the special duty of the *Locomotive Inspector* to see that the drivers' sight of signals is good, and that the signals are fixed at a suitable distance from the fouling points. It will be the duty of the *Signal Inspector* to see that the points and signals are placed in such a position as to be satisfactorily worked, are suitably arranged, and in accordance with the plan.

APPENDIX II.

LONDON AND NORTH-WESTERN RAILWAY.

Signal-Department Regulations.

All employés of the Signal Department must make themselves thoroughly conversant with the following Regulations, which must be strictly observed, to ensure the safe conduct of the work of the department:—

Regulation I.

Cleaning and Repairing Locking Apparatus, Facing-Points, Locks, &c.

When cleaning or repairing a locking apparatus, or the signals and points connected with it, necessitating their disarrangement, the following regulation must be carried out by the signal-fitter or other man sent to do the work.

Before interfering with the locking apparatus, all distant signals must either be disconnected or the levers in the cabin working them fastened in their danger position; and, before interfering with points, signals, and their connections, the distant signals for the roads affected must be fastened in their danger position. When it is necessary to disarrange the locking apparatus at a junction or station where there are facing points, the home or junction signals, as well as the distant signals, must be fastened to danger. When a facing-point or bridge bolt has to be disconnected from the cabin, the home or junction signals for the roads affected must also be fastened to danger, as well as the distant signals. At large junctions, however, where there are a number of facing points, and only one has to be disconnected, the distant signals must be fastened at danger; but special instructions will in each case be issued by the Inspector as regards the fastening of the home signals to danger. When this has been done, the signal fitter or other man must inform the signalman that he is ready to commence the work, when the signalman will, on seeing that the flagmen are properly placed and instructed, enter in the Train Register Book the words "Locking disarranged," with his signature, the fitter adding his signature also.

After this entry has been made the signalman will be responsible for working the frame as if the whole of the locking was absent, and he will do so until the fitter has informed him that the work is completed, when he will enter in the Train Register Book the words "Locking restored," the book again being signed by the signalman and the signal fitter.

When working at a signal box controlling facing-points, the signal fitter must report to his Inspector every case where Rule 149A is not strictly adhered to.

The Signal Inspector will, previous to the work being done, instruct the fitter as to whether any of the facing-points or trap-points may be spiked over during the progress of the work, in which case the fitter must see that the flagman or other man appointed has properly secured the points before he commences his work.

REGULATION II.

Locking not to be interfered with except on Sundays.

No locking-frame at a place where there are facing-points, no facing-point, facing-point lock, locking-bar, or bridge bolt, is to be disarranged for the purpose of cleaning, oiling, or ordinary repairs, on a week-day, under any circumstances whatever. Such work must invariably be carried out on a Sunday, and Regulation I. strictly adhered to. This Regulation will also apply to places where the traffic is heavy, although there may be no facing-points.

REGULATION III.

A list of junctions and stations will be exhibited in each stores-shed, showing where cleaning, oiling, and ordinary repairs, necessitating the disarrangement of locking, &c., may be carried out on week-days. The district Signal Inspector will appoint a day for the work, give the usual slackening notice, and arrange for flagmen; the work may then be carried out, Regulation I. being strictly adhered to.

REGULATION IV.

When it is absolutely necessary on a week-day to interfere with locking or connections, as mentioned in Regulation II., on account of breakage or failure likely to endanger the safety of the line, the necessary repairs must be carried out without delay. The fitter or chargeman, before commencing work, must apply to the station-master for a flagman, or, if at an intermediate box, application must be made to the signalman on duty, and should a flagman (platelayer) not be at hand, the fitter or chargeman must send his assistant for a platelayer, who will receive his instructions from the signalman. The flagman having received his instructions, the work may be commenced, Regulation I. being strictly adhered to.

REGULATION V.

Under no circumstances must a lever in a signal cabin be moved by Signal Department men, even with the sanction of the signalman on duty. Should a fitter require a lever moved, he must request the signalman to do it; and under no circumstances whatever must a fitter or other person belonging to the Signal Department instruct a flagman.

REGULATION VI.

No locking frames, or point or signal connections are to be disarranged for the purpose of cleaning, oiling, or ordinary repairs, without the permission of the district Signal Inspector, who will appoint a day, and make arrangements through the Signal Superintendent for the necessary flagmen, in accordance with Rule 149A, and for the issue of a notice to engine drivers and others.

REGULATION VII.

Signal fitters, chargemen, and others, must make themselves specially acquainted with Rules 144, 145, 146, 147, and 149A in the Company's Book of Rules, and see that the instructions contained therein are strictly carried out.

Regulation VIII.

All men belonging to the Signal Department must, before starting work at a signal cabin, enter the time in the Train Register Book and sign their name, and they must again enter the time and sign their name when their work is completed for the day; they must then fill up their time-sheets, entering the date, their name and grade, the description of the work, and the time as given in the Train Register Book, and present it to the signalman on duty for signature, who will sign it after satisfying himself that the entries are correct.

Regulation IX.

Chargemen and their assistants must give special attention to the connections working facing-points, and facing-point locks, which should be carefully examined every time a place is visited, and any weakness or fault at once dealt with.

Regulation X.

Chargemen and their assistants must frequently examine point-rod adjusting screws. Detector-holes are provided in the barrel of each adjusting screw, and the rods are centre-punched, and should the screw be found adjusted beyond the detector-hole, arrangements must be at once made for the rod to be lengthened. The screws for facing-points and facing-point locks must receive special attention.

Regulation XI.

When painting signal arms, painters must be very careful that they do not pull the signal-arm down, as such a practice is liable to lead to serious consequences.

Regulation XII.

Chargemen and their assistants, when cleaning cranks, wheels, &c., are cautioned against leaving the box-lids too close to the line, several mishaps having occurred due to a neglect of the precaution.

Regulation XIII.

All Signal Department men are cautioned against leaving tools or other materials on station platforms, several accidents to passengers, and claims against the Company, resulting from a neglect of the precaution.

Regulation XIV.

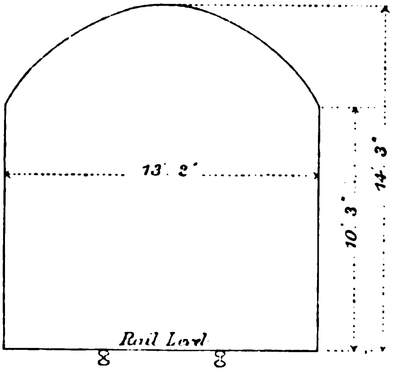
In carrying out signal alterations, great care must be taken that the old signals are kept in their danger position until the new signals are brought into use.

Regulation XV.

When it is necessary in hoisting signals or carrying out other work of the department to have guy-ropes across the line, under no circumstances must a train be allowed to pass unless it has previously been brought to a stand; and to avoid delay to passenger trains, such ropes, when practicable, should be cleared away at least ten minutes before the time the train is due.

REGULATION XVI.

A diagram is given below, which shows the clearance space required for a passenger line, or goods line, and Inspectors must see that no signal-cabin, signal-post, balance-weight, or other obstruction comes within the space dimensioned, and chargemen and others must report to their Inspectors any case where the necessary clearance has not been allowed.

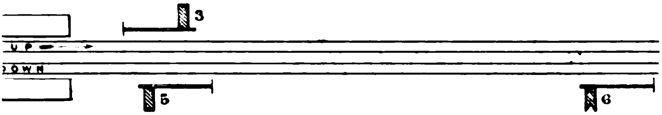


REGULATION XVII.

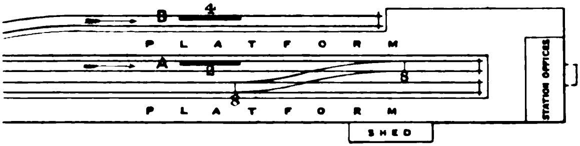
Wooden covers or boxing over facing-point locks, or other apparatus, in the 4-feet, must not stand higher than 1 inch above rail level; and if the covers are hinged, they must not stand more than 3 inches above rail level when thrown back. Chargemen must report any case where this regulation has not been adhered to.

[DISCUSSION.

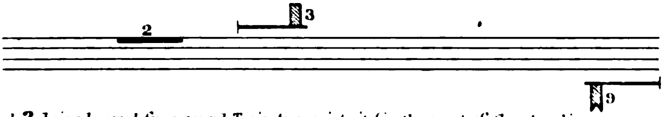
r at Various Places.—



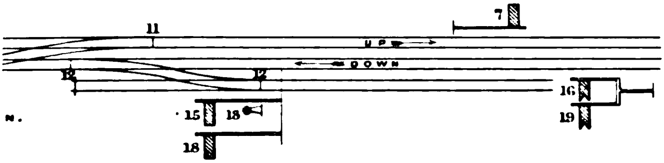
the first Train has left the Station. The Protection Bar being actuated by the same
n on the Protection Bar 5 has the same effect upon Signals 5 and 6 for the Down line.



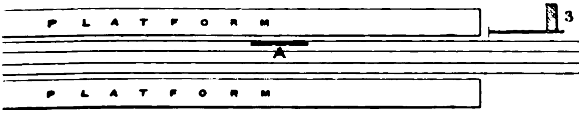
l Train, while Road **A** *is occupied. In a similar manner a Train standing at the*
A *and the tail end of it foul of Crossing* **C**, *and consequently on the Protection*
at the Platform Road **B** *and the tail end of it foul of Crossing* **C**, *and consequently*



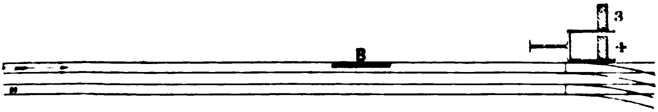
d **2** *being lowered for a second Train to run into it (in the event of the standing*
al **7** *on the Protection Bar 8 prevents the Down Signals 8 and 9 being lowered*



2, 3 *and* **18**, *so that in the event of a Down Train standing at the Starting*
r **B C**, *and consequently standing on the Protection Bar* **D**, *prevents Signals*
rain standing at the Starting Signal 17 with the tail end of it foul of
es Signals 15 and 16 being lowered for Road marked **A**. —



the rear. In this case the ordinary locking prevents these two Signals
ing simply a slotted link at the Bar. The wires are led from the Cabin



nd the Protection Bar **B** *controls Signals 1 and 2. The wires are led*
standing in the Station or waiting at Signals 3 and 4 of the Junction ahead.

THOS KELL & SON LITH LONDON

Discussion.

Mr. F. W. WEBB considered the Paper might be taken fairly to represent the mode of Signalling on the London and North-Western system. He would, however, make a few remarks on the maintenance of the locking now adopted on the line. Plate 2, Fig. 3, represented one of the levers in the large box at Crewe, put up in March, 1879. It was the first large box in which a scheme was contrived to relieve the weight of the locking, and the lever was introduced so that half the locking bars were upwards and half downwards. There then remained only the friction to overcome. Since the box had been erected the average number of levers pulled over in twenty-four hours was 6,930, making the total number of movements 15,627,150; and, excepting in the case of fifteen of the small tumblers, out of one hundred and forty-four there had been nothing done to the box in the shape of repairs. Care was taken to make the parts of the strongest possible form, and those in tension were, as a rule, of wrought iron; all the joints were case-hardened, and everything was got up as carefully as a reversing lever for a locomotive. The last contrivance, which was due to the Author, was represented in Fig. 13A, and it would, he thought, tend to great safety in the working of the facing-points. Instead of dividing the locking-bar with a differential plunger, which he suggested some years ago, the divided locking-bar was carried to the outside of the line, one bar from one point and the other bar from the other point. When in the exact position that they should occupy, the tail-end of the lever working the signal could pass into a slot which was half in one bar and half in the other. Until that was the case it was impossible to pull off the signal. The wires might be broken, but the last operation of lowering the signal could only be effected when both points were in the proper position. In 1874 it was stated that the company had spent about £1,000,000 in interlocking. The total amount spent to the present time was £2,331,313. More than half the interlocking on the London and North-Western system was now the same as that shown in Plate 2, Fig. 3. Strong gear having been used, the maintenance had been reduced. In the half-year ending 1874 the amount spent was £16,331; and in the same period in 1884 it was £17,233; but spreading the amount over the whole number of levers the cost of maintenance for the half-year ending 1874 was £1 3*s.* 8*d.* per lever, and in 1884 Mr. Webb.

Mr. Webb. it was 13*s.* 10*d.* The amount included not only ordinary maintenance but all extensions the cost of which did not exceed £10. He had also carried out another adaptation for branch lines, namely, the use of Annett's key. That had enabled the locking on the North-Western Railway to be pushed on at a more rapid rate than it otherwise could have been done. When the signalling was given into his charge the first thing he endeavoured to do was to reduce it to a system. He had found every variety of lamp in use, some with candles, some with olive oil, some with gas, some with wicks 2 inches wide, some with wicks 1½ inch wide, and down to ½ inch. Ultimately a lamp was schemed for burning petroleum oil. There were now over fifteen thousand of those lamps, all uniform in wick and every other appliance, at work on the line. Since they were introduced fewer signal-lamps had gone out, and altogether there was less trouble with them. He had brought a lamp with him in order to explain its construction. In trying to burn petroleum, some trouble was at first experienced with the lamps in windy weather, and also in carrying the inner cases to put in the lamp cases after they were lighted. He had with him a specimen burner which he had himself devised. The air was admitted through the centre of the oil cistern, and the deflector plate was so arranged that none of the air could get to the burner without coming under the deflector plate, which, while it prevented a direct current to the burner, prevented the oil-reservoir from becoming unduly heated, as all the air to support combustion had to come between the burner and the reservoir, so that the greater the draught through the lamp the greater was the current of cold air pouring on the top of the reservoir to keep it cool. The oil was burned without any chimney, and the lamp was satisfactory in every way.

Mr. Farmer. Mr. J. S. Farmer said if the Paper had been confined to the theory and practice of Signalling on the London and North-Western Railway he should have had for it no words of disparagement. The Paper contained a great deal of useful information, especially the Appendices. Some excellent rules were laid down for the guidance of those connected with the Signalling Department. He congratulated the Author upon the Paper he had produced, as he had proved by it that he had qualified himself to be called a Signalling Engineer. But the Signalling Engineer was not a thing of to-day, nor, as the Paper seemed to infer, was it something to be arrived at in the future. He himself claimed to have practised the profession of Signalling Engineer with no little degree of success, with his partner Mr. Saxby, for the last

Mr. Farmer.

twenty years. But it was with regard to the things outside the theory and practice on the London and North-Western Railway that he desired to say a few words. Using the words of a celebrated phrasemonger, "With these things before me I say I cannot close this book and say that I will look into it no more," he found the greatest fault in the Paper to be one of omission. The Author had omitted, probably unintentionally, to credit Mr. Saxby with the original invention of the locking-apparatus in 1856. The same forgetfulness had been exhibited by Mr. Rapier, who wrote a Paper on the subject of railway signals in 1874, when Mr. Imray remarked that the Paper was like the play of "Hamlet," with the part of Hamlet left out.[1] The only thing mentioned both by Mr. Rapier and by the Author as anticipating the Saxby apparatus of 1856, was an arrangement that was discovered at Retford. It was accurately described in Mr. Rapier's Paper. There was on the ground, but not in the signalling-cabin, a piece of iron connected to a pair of points, and when those points were moved to and fro the piece of iron moved to and fro with them. In the piece of iron there was a hole, and the downright rod of the signal, when it could enter the hole, showed that the points were set in the proper position for the signal. He had a diagram of the arrangement actually in force at that particular junction, in connection with which it was stated: "It was in no sense a locking arrangement for preventing accidents at junctions, as for instance, although the piece of iron had relation to signal B, it made no pretence whatever of influencing or controlling any of the other signals, so that actually the points might be standing in their normal position, which is right, as before mentioned, for the traffic to pass from Gainsborough to Manchester, and yet there would be nothing to prevent the contradictory signal A, from Gainsborough to York, from being given." In fact it was possible that all the signals might be down together. With regard to the Saxby apparatus of 1856, Mr. Rapier had spoken of it as being confined to a *pari passu* movement of the point and signal. He had a diagram and a description of the apparatus, which was fixed at the Bricklayers Arms Junction of the Brighton Railway, of which he was at the time Assistant Traffic Manager, and he could therefore speak from personal knowledge. It consisted of six pairs of points and eight signals, and it was thus described: "No signal can be given inconsistent with the position of the points. Any number of points may be worked in connection with the signals and distant signals.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 195.

Mr. Farmer. Absolute certainty of correspondence of all the points and signals is ensured." From that time to the present there had been no improvement sought or attained in interlocking as a principle. It was for the purpose of ensuring that the out-door signals, which would guide the engine-drivers, should be incapable of being contradictory to one another, or in contradiction to the points themselves. With those remarks he hoped he had set at rest the question of the first and true inventor in this case. With reference to the 1856 patent, he might mention that for the first time Mr. Saxby applied to the levers for working points and signals a spring catch. The spring catch was a well-known instrument on the locomotive, used on the lever of the reversing-gear, but it was then, for the first time, used by Mr. Saxby in connection with the levers of points and signals. But it was not until 1867 that Mr. Saxby made the spring catch the actuator of the locking-gear, and thereby obtained what was now commonly known as "preliminary action." He believed it was the President of the Institution, Sir Frederick Bramwell, who had said of it, that "the intention of the signalman to move a lever, as expressed by the grasp of the spring catch handle," actuated the locking-gear, and locked all those levers which should be locked, and unlocked those which should be unlocked, before that lever was itself capable of being moved. That, he thought, was one of the greatest improvements in locking-apparatus, as a machine. The Author of the Paper had naively remarked—he supposed he alluded to that particular arrangement which was patented by Mr. Saxby—that it was one of those patents that hampered the mechanical engineer at Crewe, in his endeavour to arrive at the best kind of apparatus. One very important matter in the progress of the science of railway-signalling was, he thought, the combination of the interlocking and the block systems, so that they were made actually interdependent in working. The Author had referred to the subject, but hardly gave it the prominence it deserved. He had stated, "On trunk lines, where the block stations are far apart, and the trains are run at greater intervals of time, the necessity for such apparatus is hardly felt; but as traffic increases, and block stations become more numerous, it will no doubt in certain cases be advisable to adopt some such additional means of security." Probably many persons remembered the terrible accident that happened at Arlesey through contradiction between the telegraph instrument and the out-door signals. The arrangement of uniting the interlocking with the block system would have prevented that most serious calamity, and the time, he thought, would soon come when it would receive at the hands, especially of railway Signalling Engineers, more consideration than it had received at present. Mr. Webb had spoken of the very great expense of the interlocking system, but he had said nothing of what it had saved. It would have been only a graceful tribute to the originators of the system, if something had been said on that point. One of the most eminent administrators of railways in this country, Mr. Samuel Laing, Chairman of the Brighton Railway Company, speaking of that line, had stated, "We have adopted all the modern improvements, the block system, the Westinghouse brake, interlocking points, signals, &c., and I believe the official returns show that we have been among the first, if not the very first, of the great railway companies, in carrying out the recommendations of the Board of Trade. The result is that we have reduced preventable accidents to a minimum, and have for a long time past been singularly free from serious accidents to our trains." He had spoken of the omission of the Author to notice Mr. Saxby's original invention; he was naturally more diffident in pointing out the omission to notice two inventions of his own. One was Farmer and Tyer's electric slot. It was said in the Paper that Mr. Gill was the inventor of the slot signal in 1862, but any one who would refer to the specification of Mr. Saxby's patent of 1856, would find that the slot signal was an essential part of his invention. The electric slot was not so called because it was a slot literally, but because it had the same functions as the mechanical slot. The mechanical slot enabled two or more men to control one and the same signal. Any man could place the signal and keep it in the danger attitude, but it required the concurrent action and consent of all the men before the signal could be lowered to indicate safety. The electric slot enabled that to be done irrespective of distance. The contrivance might be seen at the exhibit of Saxby and Farmer at the Inventions Exhibition at South Kensington. There was also at the same exhibit another invention which he claimed, namely, the Duplex Detector for facing-points. The simple principle of it was this, that the movement of the point lever dominated the direction in which the rod that worked the facing-point lock should be moved. In one position of the points the rod was pushed, in the contrary direction it was pulled, with a plunger into an appropriate hole in the cross-bar of the facing-points. Mr. Farmer.

Mr. Spagnoletti. Mr. C. E. Spagnoletti agreed with the Author as to the necessity of a railway having a Signal Department of its own, and he believed it was generally admitted that such an establishment was desirable, from the fact that all large companies had such a department. It

Mr. Spagnoletti.

was an all-important one with regard to the safe working of the traffic, and it had now become especially so, owing to the increase of traffic, the number of shunting-yards, station-yards, and junctions. Such a department should, of course, be under the direction of a well-qualified and experienced mechanical engineer versed in railway-working. It might be very advantageous in future to have the two signal departments, the mechanical and the telegraphic, united and under one competent head. It would undoubtedly be a great advantage to the telegraph engineer to be a good mechanic; and it would be of equal advantage to the mechanical engineer to be a good electrician. The two systems of signalling were now so intermixed, that one was almost a necessity to the other. According to the present system, all the signals that were out of sight of the men working them had, attached to them, electrical repeaters, which were much preferred to mechanical ones on account of the lever being relieved of weight. There was one thing he did not quite understand in the instructions given by the London and North-Western Company; he could not see why "electrical repeaters should be avoided as much as possible," because they were most excellent things, and kept the signalling working with the greatest nicety. They showed at once, when the wire was expanding or contracting, and the man had a direct communication from the signal-arm, so that he knew whether it was "up" or "down," or in an "intermediate position." Some companies thought it also necessary (and he agreed with them) that the lamp should be indicated; because it was perfectly useless at night to have a signal-arm working, unless there was a light behind it to show the signal and position of the arm by the colour of the glass to the driver. Accordingly indicators were now used to show the condition of the lamp, whether it was "in" or "out." Then there were signals for gate-men and from signal-boxes to the stations; and, lastly, there was an electrical apparatus locking the levers from one station to another, which, as Mr. Farmer had said, would no doubt be more extensively used than it had been, as soon as confidence was felt in that mode of working. The locking system used on the Great Western Railway was exceedingly simple in its mechanism. The chief points were, that there should be as few wearing parts as possible; that those parts should be easy of interchange, and, lastly, that there should be very close locking, that was, that the first movement of the lever should lock all the other levers that it was intended to lock, and when the lever was put back into its place, the last movement should unlock the signals which

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were previously locked. He observed, in the instructions given in the Paper, the statement that the signals at an elevation higher than 45 feet should have also a lower arm called a "fog arm"; but it was also stated that, "A single lamp only is necessary, to be opposite the bottom arm when practicable." He did not quite understand whether it was intended that only one lamp should be used, and that it should be at the bottom arm, or whether its position should be changed according to circumstances. Fogs were comparatively so few, that one would imagine that, in the case of a signal 45 feet high, it would be more frequently a guide to the driver than the lower one, and therefore should be provided with a lamp.

He had been permitted to exhibit a system of electrical locking, and would take the opportunity of explaining it, as by this addition a further advance was made in the right direction. By the present system the signalmen had perfect control over the levers, and could manipulate them as they desired; and if a signalman laboured under a mistake he could alter the levers at will, and might so do wrong; but with electrical interlocking it was impossible for this to occur, as the train itself controlled both men. On double lines the man in advance took the lock off the starting signal at the station in the rear. Having done so the signal could be lowered for the train to proceed, and on its being put back to danger, after the train had left, it could not be lowered again until it was unlocked from the station in advance, and the man at the station in advance could not unlock this signal again until the train occupying the section had arrived at his station, or any part of it required by the traffic superintendent, and passed over the resetter; so that two trains could not possibly be in the same section, even if both the signalmen should attempt to admit a second. The instrument by moving a switch-handle was at once converted into an instrument for working "single lines," in which case not only must one train be prevented from following another in the same section, but a train must not be allowed to enter the section in the opposite direction. By this instrument when a train was admitted from either end, both signalmen were powerless to admit another at either end, until the one occupying the section was clear of it: and on its arrival at the given and required place it reset the apparatus, so that the man at either end might allow another train to enter the section, but two trains could not possibly be admitted into the section at the same time. This system was applicable for locking the levers of draw- or swing-bridges over

Mr. Spagnoletti. rivers and docks; also for locking intermediate sidings and level-crossing gates; it had been working satisfactorily for nearly four years, and was being tried on several lines very successfully.

Mr. Timmis. Mr. I. A. TIMMIS said that the importance of railway signalling might be summed up somewhat briefly. Wherever civilization existed there must be railways, and civilization would not permit railways unless they were properly worked and controlled. Looking at the enormous system of railways throughout the world, and the amount of brain-power and wealth expended on them, he willingly admitted that they had been brought to a high state of perfection, and on no system was there a higher degree of excellence than on the London and North-Western Railway. It was pretty well known, however, that he was not altogether in favour of the system in use on that railway. The Author of the Paper had stated that mechanical and civil engineers and the world in general were very often hampered by inventors. Being himself an inventor, and knowing many others, he wished to say on their behalf that it was never their desire to stand in the light of those whom their inventions ought to benefit, and the man who did stand in that position was certainly doing the greatest possible harm to himself. The inventions with which he was connected were the working of railway points and railway signals, controlling them, and also controlling the whole line from station to station by the electric current. The current was not the electric current used in ordinary telegraphy, which sent but a small fraction of an ampere of electricity through the wire with a high electromotive force, but a sufficient current sent at a low tension, so that no local and electrical disturbance could have any upsetting influence on its working. The first question to which he desired to draw attention in connection with the system he advocated was that of signal cabins. The Author had alluded to a signal cabin, for working one hundred and eighty levers, that was 96 feet 6 inches long by 12 feet wide. With the small levers that they used, and the different sized instruments that were found necessary, a signal cabin need only be 25 feet by 8 feet, and that would leave plenty of room for the signalman. Reference had been made to the enormous number of mechanical movements of levers taking place in the course of a year. It appeared to him that it was decidedly preferable to work a lever 6 inches long (which was all that was required for his system) instead of one of the very long levers referred to in the Paper. As to the question of signals, owing to the necessity of getting distant signals further and further away from the signalling cabin, it had become a very difficult question

Mr. Timmis. how to work them accurately in consequence of the unequal expansion and contraction of the wires at different temperatures. Of course with an electric current it did not matter whether the signal was 100 yards away, or 5 or 6 miles; there was no mechanical or electrical difficulty in the matter. Many years ago it was the practice to work distant signals at three positions, the horizontal position for danger, at an angle of 45° for caution, and the vertical position for "go ahead," but that system had been practically abandoned. He thought, however, that it would be advantageous frequently to work distant signals from those three positions. When two stations A and B were 6 or 7 miles from each other, it was found desirable to have a signal-cabin half-way between them where a man was always at work with a set of block instruments. That of course was a great expense, but by means of a distant signal put in the required position, one from station A and the other from station B, all the mechanical appliances, including the magnet, were locked up so that they could not be touched; the current was sent overhead or by the wire underneath, and nothing could possibly get out of gear. There was no natural force as reliable and so little likely to get out of order as dynamic electricity or magnetism. A second distant signal might be used, and the two signals might be placed wherever it was found most convenient and economical. It might be said that it was not safe to have a signal where a man in the box could not see it, but he ventured to say that that was an error. He had done something in the way of driving express trains, and he knew that at night it was often impossible for a man in the signal cabin to see the distant signal. There was then needed, as had been pointed out by Mr. Spagnoletti, something in the signal cabin to show the man the exact position of the signal, and what could be more trustworthy than a distant signal which was pulled down by the long-pull magnet? The current through the magnet went back to the signal cabin and worked the repeater, and it was evident that if the repeater was down the signal must be down also. If the current was broken, not only did the repeater in the cabin go to danger but the magnet and the signal went to danger also. Then there was another advantage in the system, that anything might go wrong with the mechanical arrangement but nothing could go wrong with the electric current. The wire might be broken, but that would not interfere with the system or with the correctness of its working. If anything failed the signal went to danger. As to the question of interlocking, there was nothing so easy to work as a current of

Mr. Timmis. electricity. If five outlets from a main were opened it would flow along those five outlets, and it would flow along five hundred. All that was required was to regulate the strength of the current. Suppose there were ten signals and it was wanted to work 1, 3, 5; 1 the distant signal, 3 the home signal, and 5 the departure signal; 2 and 4 being the home and departure signals on the branch line. The current was sent to 5 through 4 when the lever 4 was back; so that if 4 was pulled forward it was utterly impossible to lower 5. The same result occurred with 3 and 2; and if it ought to be impossible to lower the distant and home signals of the main line, say 9 and 10, when running from 5 on to the branch, then the current to lower 5 would not only be sent through 4 when back, but through 9 and 10 also when back. It was therefore impossible to lower the wrong signal. In working points two magnets were used, one that pulled the points over in one direction, and the other that pulled them in the opposite direction, and the locking-bolt. The locking-bolt was shot into the cross-bar; when it was home in the cross-bar it completed the circuit, which enabled the signalman to lower the signal that covered that pair of points. Whichever way the points were opened the same process was followed. If the signalman saw the signal repeater down in his cabin, he knew not only that the signal was down, but also that the points were locked. Of course the points could be at any distance. He had seen station-yards with a number of sidings that had been almost throttled in order to get them within reasonable distance of a signal-cabin. But if it was possible by a wire to carry a current of electricity 40, 50, or 100 yards, there would be a saving of rails and of awkward turnings, besides a saving in many other points. It might be said that the cost of the electric current was expensive; but he was prepared to demonstrate that the cost per signal for twenty-four hours, presuming that it was lowered one hundred and fifty times a-day, and that it was held down for one-half the time, was not more than a farthing. He was not sanguine enough to expect that he could induce all the Signal Engineers of the kingdom to adopt his system; but he hoped they would consider its merits honestly and fairly. There was great difficulty in advocating a new invention at any time; but that difficulty was enormously increased when there was already in the field a system so efficient and long-tried.

Mr. Blackall. Mr. THOMAS BLACKALL said he had for many years been connected with the signalling of the Great Western Railway, to which he belonged, for which a locking-frame of a very simple character had been designed; he might say, however, that there had never been any failings or complaints in regard to locking. The method had been in use about fifteen years, and there had been no difficulty in regard to repairs. He therefore concluded that the machine had worked satisfactorily. He wished to direct attention to the great importance of facing-points, which were worked at a considerable distance, the present limit being 150 yards. Various appliances had been used for the purpose of ensuring greater safety, and there could be no doubt as to the necessity of such appliances. One important point deserving of attention was the periodical renewal of all fittings and connections. It was well known that, after having run a given number of miles, locomotive- and wagon-axles were renewed, and he thought the same should be done with regard to facing-points; they should be properly registered and renewed at certain intervals. The additional appliances required might be of a very simple character. He could hardly go so far as to recommend that there should be another line of rods working the points, which would be adding another link in the chain, and would need looking after and repairing. The question of repeating the distant signal was also an important one. When he was first acquainted with the working of railway-signals, it was a difficult matter to fix a mechanical repeater that would accurately show the position of the signal-arm when not seen. There were also difficulties when the electric repeater was first introduced, especially in indicating the lamp; but that difficulty had now been overcome. For the last four or five years the use of the electric repeater had been perfectly satisfactory. Of late years the working of distant signals had been easy. It was often necessary to place distant signals 1,000 or 1,200 yards from the cabin, and the difficulty of working had been very great; but by using a lighter wire, by giving the signalman in the cabin perfect control of the wire, and by the electric repeater, there was now no difficulty in working distant signals. The rules given in the Paper for carrying out railway signalling appeared to him to be of a character that would ensure safety, and prevent accidents. Mr. Blackall.

Mr. J. W. Fletcher observed that the different departments of a railway company were more or less dovetailed into each other, and it was only with very small railway companies that one man could supervise the whole. With large systems it was essential that each department should have a responsible head. He did not think the signal and telegraph departments should be merged into one, as two-thirds of the work of the telegraph department would be quite foreign to the signal engineer. A telegraph-inspector, Mr. Fletcher.

Mr. Fletcher. assuming that he had ample time at disposal, would be a long while before he would master the working and mechanical details of the signal-department; and a signal inspector would be a much longer time in acquiring the knowledge to become an efficient telegraph inspector, for the latter had not only to possess a knowledge of telegraph engineering, but must also be a fair electrician. There was quite enough for himself and staff to do in properly attending to their own legitimate business, and he was satisfied that the signal department of the London and North-Western Railway was in the same position. With regard to "lock and block," the order given by the Author in the Paper was incorrect. Mr. Preece came first; this gentleman's name was so identified with electrical matters appertaining to railways and otherwise, that although he had no date of any arrangement of his, he had no doubt there was some appliance of the kind. Mr. Tyer took out a patent in 1869, and Mr. Baines in 1871, and, although he was not aware at the time (September, 1872) of the existence of these, he wrote to Messrs. Saxby and Farmer, stating that he had an arrangement for an electrical "lock and block," which was more particularly applicable to the 3-wire system. He was asked by that firm whether he could lock the "levers that actually worked the visible signals, or merely lock the levers of other electrical levers." Upon his replying that he could lock the levers actually working the visible signals he got a final reply from them, an extract of which was as followed:—"Our speciality, as you are aware, is the interlocking of points and signals at stations and junctions by mechanism, and beyond that we do not see our way at present. We do not doubt your ability to effect what you intend, but the thing is, will railway managers concede its utility and adopt it?" This letter was dated the 7th of October, 1872. So far as he had been able to ascertain, the different patents for this object came in the following order:—

No.	Date.	Name.	Description.
2,907	6 Oct. 1869	E. Tyer	Interlocking signals and block instruments.
779	22 Mar. 1871	W. Baines	Working signals or switches on railways.
2,923	3 Oct. 1872	C. W. Siemens . . .	Telegraphic instruments and signalling apparatus.
333	28 Jan. 1873	A. Bernstein . . .	Apparatus for controlling switches.
820	6 Mar. 1873	W. Baines	Working railway switches, points, and signals.
2,796	25 Aug. 1873	J. J. Nickoll . . .	Signalling apparatus.

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No.	Date.	Name.	Description.
2,423	10 July, 1874	J. S. Farmer & E. Tyer	Safety signals for railways.
662	23 Feb. 1875	W. R. Sykes . . .	Signalling on railways.
206	16 Jan. 1877	C. Hodgson & J. Imray	Railway points and signals.
400	31 Jan. 1877	C. Hodgson . . .	Blocking and interlocking on railways.
1,326	4 Apr. 1878	C. Hodgson . . .	Interlocking apparatus for the points, &c., on railways.
2,549	25 June, 1878	E. W. Stoney & G. K. Winter	Working railway switches and signals.
5,005	6 Dec. 1878	J. S. Williams . . .	Apparatus for railway signalling.
1,044	17 Mar. 1879	E. Tyer	Electric apparatus for signalling on railways.
4,170	15 Oct. 1879	C. Hodgson . . .	Interlocking the telegraphic instruments with the points and signals on railways.
1,907	10 May, 1880	W. R. Sykes . . .	Railway signal apparatus.
2,183	28 May, 1880	C. E. Spagnoletti . .	" " "
1,789	26 Apr. 1881	J. W. Fletcher . .	Electric lock for sidings, &c. (also applicable to "lock and block").
198	13 Jan. 1882	J. Radcliffe. . . .	Electric block signals.
677	11 Feb. 1882	W. E. Langdon . .	Interlocking electric and other signalling apparatus.

With regard to the electric lock for sidings, the following regulations were in force:—

London and North-Western Railway.

Instructions to Signalmen and others working the points and electrical apparatus between .

Electric gong code from station "A" to station "B"—

Call attention and acknowledgment . .	1	stroke on the gong.
Points unlocked	6	strokes (thus, 2—2—2).
Clear " line" at siding for train to pass	7	"
Special "train entering section" signal .	8	" (thus, 2—2—2—2, or 4—4, as shown).

Electric gong code from station "B" to station "A"—

Call attention and acknowledgment . .	1	stroke on the gong.
Unlock points	6	strokes (thus, 2—2—2).
" line" cleared; points replaced, and indicator turned to "siding, locked, signals unlocked"	7	"

Electric gong code from "siding" to station "B"—

Call attention and acknowledgment . .	1	stroke on the gong.
Unlock points	6	strokes (thus, 2—2—2).
Engine gone forward to station "B" .	3	" (thus, 2—1).
Train " " " . . .	4	" (thus, 3—1).
Signal in error	5[1]	"
" line" cleared, points replaced . .	7	"
Inspector's signal for testing apparatus .	16[1]	"

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[1] Signals marked thus must be repeated before they can be considered as understood.

Mr. Fletcher. Electric gong code from station "B" to "siding"—

Call attention and acknowledgment . .	1	stroke on the gong.
Points unlocked	6	strokes (thus, 2—2—2).
Signal in error	5[1]	"
Clear " line" for train to pass . .	7	"
Inspector's signal for testing apparatus .	16[1]	"

The system of working will be as follows:—

1. Before a train leaves station "A" which has to call at the "siding," the signalman must signal it on to station "B," as laid down in the rules for absolute block working, giving, however, the special signal of eight strokes on the gong (thus, 2—2—2—2) as "train entering section" signal, for the information of station "B" signalman that the train is calling at the siding.

2. The signalman at station "A" will then allow the train to proceed to the "siding," and, as soon as it has passed his signals, will electrically release the points at the "siding," and thus lock his own signal levers.

3. If during the time the train is occupied at the siding the signalman at station "A" receives the "be ready" for an important train approaching on the "   line," he will advise station "B" by giving seven strokes on the gong, station "B" transmitting the same (seven strokes) to the "siding," this signal being acknowledged by one stroke in each case; and the shunter or brakesman must, as soon as possible, finish his work and send forward the train to station "B," or shunt his train into the "siding."

4. When the shunter or brakesman has completed the shunting at the "siding," and the engine or train is ready to start towards station "B," he must call the attention of the signalman at station "B" by giving one stroke on the gong, and, having obtained an acknowledgment, he must give the code of three strokes (thus, 2—1) or four strokes (thus, 3—1), as the case may be. After this has been acknowledged by the signalman at station "B," the shunter or brakesman must close the points, give seven strokes on the gong, and then proceed on his way. On the engine or train passing station "B," the signalman at that place will transmit this signal (seven strokes) to station "A," and turn his indicator to "siding locked, signals unlocked," which station "A" will acknowledge by one stroke on the gong, and the section to station "A" is then to be cleared, in accordance with the rules laid down for absolute block working.

5. If the train is one which is going to remain at the siding for any purpose, the signalman at station "A" must signal it on to station "B," as laid down in the rules for absolute block working, giving, however, the special signal of eight strokes on the gong (thus, 4—4) as "train entering section" signal, for the information of the station "B" signalman that the train is going into the siding to remain. The signalman at station "A" will then proceed to act as directed in paragraph 2.

6. As soon as the whole train has been put into the siding, and the main line is clear, the shunter or brakesman must close the points and give seven strokes on the gong to station "B," who will acknowledge by giving one stroke on the gong, transmit the same (seven strokes) to station "A" and turn his indicator to "siding locked, signals unlocked," which station "A" will acknowledge by giving one stroke on the gong. The signalman at station "B" will then clear the section to station "A," in accordance with the rules laid down for absolute block working.

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[1] Signals marked thus must be repeated before they can be considered as understood.

Mr. Fletcher.

7. When the train is ready to proceed from the "siding" towards station "B," the shunter or brakesman must call the attention of the signalman at station "B" by giving one stroke on the gong, and, having obtained an acknowledgment, he must give six strokes on the gong (thus, 2—2—2), "unlock points," which station "B" will transmit to station "A" (providing he has not accepted a "be ready" signal for another train on the " line," in which case he will wait until the section is clear); and if the signalman at station "A" has no other train on hand to send forward, he will electrically release the points at the "siding" (thus locking his own signal levers), and will reply to station "B" by giving six strokes on the gong (thus, 2—2—2), "points unlocked." Station "B" will then proceed to block the " line," as laid down in the rules for absolute block working, and then transmit the signal, six strokes on the gong (thus, 2—2—2), "points unlocked," to the "siding." The shunter or brakesman will then open the points and despatch the train, advising the signalman at station "B" that he has done so by giving four strokes on the gong (thus, 3—1). After this has been acknowledged, the shunter or brakesman must close the points and give seven strokes on the gong. On the train passing station "B," the signalman at that place will transmit this signal (seven strokes) to station "A," and turn his indicator to "siding locked, signals unlocked," which station "A" will acknowledge by one stroke on the gong, and the section to station "A" is then to be cleared, in accordance with the rules laid down for absolute block working.

N.B.—When the work is being done by the brakesman, the engine-driver must allow him to get into the brake before starting away.

No. 1 was drawn up so as to meet all the requirements, the arrangement being worked in different ways, *i.e.*

(*a.*) Between the block-post in rear and siding.

(*b.*) Between two block-posts, with siding intermediate.

(*c.*) When the train could be put into the siding, and main line cleared.

(*d.*) When both up and down lines were obstructed as in the case of Weedon Drawbridge.

London and North-Western Railway.

Instructions to Station-Master, Signalmen, and others concerned.

Rules to be observed for opening the Canal Bridge at Weedon, commencing 12.0 noon on Monday, February 26th.

1. The Commissary of Ordnance will give two hours' notice to the station-master of his requiring the bridge to be opened, to enable him to summon the platelayers (whose hours of work are from 6.0 a.m. to 5.30 p.m., except for six weeks before and after Christmas Day, when they are from 7.0 a.m. to 5.0 p.m., and on Saturdays, when the men leave duty at 4.0 p.m.).

2. The station-master, or, in his unavoidable absence, the person left in charge of the station, must always be present when the bridge is opened, and give the requisite instructions personally to the signalman.

3. The bridge is locked with the signals worked from the signal-box, and cannot be taken off unless the signals are placed at danger; and an electrical arrangement has been fixed, giving Heyford North on the one side and Brockhall on the other, control of the lever bolting the drawbridge.

Mr. Fletcher. 4. Before permitting the drawbridge to be opened, the signalman at Weedon must block back, in accordance with the Block Telegraph Regulations, to Heyford North for the down line, and to Brockhall for the up line, and give the special signal on the gong of six strokes thus, 2—1—3, to indicate that the drawbridge is required to be opened.

5. The signalmen at Heyford North and Brockhall must then, in accordance with their instructions, electrically lock their signals for the down and up lines respectively at "Danger," and this movement will at the same time free the lever in the Weedon signal-box controlling the drawbridge.

6. The station-master (or his representative) must satisfy himself that these regulations are carried out before allowing the bridge to be opened.

7. When the line has been blocked for this purpose no train or engine must be allowed to leave the sections on either side even under the "Section Clear and Station Blocked" signal, but the traffic must be kept standing at the outside boxes until the line is again perfect and clear through the station.

8. The bridge must not be opened in foggy weather or snowstorms, nor except within the platelayers' hours of work noted above.

9. When the bridge has been completely replaced and secured, and not till then, the station-master, or, in his unavoidable absence, the person acting for him, must authorise the signalman in the station-box to give "Line Clear." The signalman must then, in accordance with his instructions, electrically lock the lever controlling the bridge, thus unlocking the signals at Heyford North and Brockhall, and give the special signal of six strokes on the gong, thus, 3—1—2, to indicate that all is right for the ordinary working.

The method of procedure was as follows:—Signals at the signal box, whence the train left, were unlocked electrically and the siding locked electrically. Instead of using at the signal box, and having to carry to the siding, an Annett's key, the insertion of an ordinary carriage-key into an aperture in connection with the locking frame at the signal box, and turning the same, was all that was necessary to lock the signals at the signal box, and release the lever working the points at the siding. As would be seen from the regulations, the train might be put into the siding, if having work to do that would occupy some time, in which case the man in charge of the train, would intimate by bell to the signalman, that the train had been put into the siding, and would then by a simple movement of the electrical apparatus, lock his lever working the siding points, and at the same time unlock the signals at the signal box in the rear. The only variation of these operations depended as to whether the train was put into the siding, or had to occupy the main line; in any case, the locking and unlocking of the signals and the siding were precisely the same; whether actuated wholly by station A and siding, station B and siding, or the whole of the three, depended upon circumstances, how the siding was situated and worked, from a traffic point of view. The arrangement might be worked by either a "closed" or an "open" circuit; the former preferably, as any failure electrically, would be on the side of safety, that was, signals locked. This electric lock had been inspected by the Board of Trade, and its use sanctioned. Mr. Fletcher.

Mr. Edwards. Mr. G. Edwards, Managing Director of the Railway-Signal Company, said it was stated in the Paper that the London and North-Western Company had, in 1873, instituted a signal department, and appointed an engineer to superintend the work and assist Mr. Webb. He was the engineer referred to, but his appointment was an independent one, and he had no connection with the shops at Crewe. The following companies were now provided with a staff of Signal Engineers and shops, and were either partially or wholly making their own signals: the London and North-Western, all their own; the Midland, all their own; the North-Eastern, partly their own; the South-Eastern, all their own; the Manchester, Sheffield, and Lincolnshire, partly their own; the Great Western, partly their own; the Great Eastern, partly their own; the Caledonian, partly their own; the North London, all their own. But the Great Northern Company was convinced that it got its work done more cheaply by contract; the Great Western was very much curtailing its own manufacture. If all the large railway companies were at once to decide to make their own signals, there would not be vacancies for six men in the whole country. He thought it undesirable that railway companies should be their own signal manufacturers, because there was a considerable outlay of capital for shops and machinery, and an expensive staff of clerks and inspectors. The great question was one of economy. The question, also, whether a contractor did his work as well as a railway company rested entirely upon the company, which had the means of supervising the work and easily ascertaining whether it was done properly or not. Two years after the London and North-Western Railway Company started its signal department, he was instructed by the Chairman to furnish him with a statement showing the cost of the work done by the Company, as compared with what the cost would have been if it had been done by the former contractors. The result of the comparison of twenty-one cabins was that the work cost the Company £10,646 8*s.* 4*d.*, and if it had been done by the contractors even at their then high schedule of prices, the cost would have been £8,809, or 17½ per cent. less. The cost to the Company did not include the carriage of materials, for which the contractors would have had to pay at least £1,000. Nine months later, in May 1876, he made a similar comparison with reference to another work, and found that it had still cost 15 per cent. more, and

Mr. Edwards. the new system had then been nearly three years in operation. A question was raised as to whether fixing out of doors by his staff had cost more than it should have done. He went into the subject with Mr. Webb, and they arrived at the basis as to what was the true percentage of fixing on the cost of materials; they agreed pretty nearly in their figures, and the amount might be taken as a reasonable one. The whole question, therefore, at the time referred to, was one of cost of material, and not cost of fixing. A railway company could not do the work as cheaply as a contractor, because it was well known to all engaged that there was a deep pocket to dip into, and there was a great deal of extravagance. The Author had stated, "In 1876 Mr. Webb proposed a locking-frame, the locking being actuated by the lifting of the lever, the catch-rod acting as a fulcrum; and in the same year he introduced the apparatus now in general use on the London and North-Western Railway, which the Author considers, both as regards design and workmanship, to be unrivalled." Mr. Edwards differed from that statement. He might be permitted to refer to a few locking-frames about which he knew something. The Saxby and Farmer's frame, with spring catch actuation, was admirable in theory, but he disliked it; it was too delicate in action, and rather complicated. The parts were too numerous, and there was not sufficient margin for wear. The apparatus made by Mackenzie and Holland was a good machine, but it was heavy and cumbersome. Mr. Webb's apparatus was very heavy; it had a great many parts, and was extremely complicated. It was so delicate, that the Author had stated that it was necessary to have cabins with more than fifty levers heated with hot water to keep up a certain temperature to prevent the expansion and contraction of the locking bars. That was certainly too delicate a machine to put into the hands of a railway signalman, who was perhaps brought up to agricultural pursuits, and knew nothing about machinery. For such a man, the machine should be simple, and have a small number of parts. With reference to the apparatus introduced by Stevens and Sons, he could emphatically endorse the statement made by the Author. It was, he believed, the simplest machine known in the present day. It had the fewest parts, and was the most effective. Mr. Edwards had at first followed in the footsteps of Mr. Webb, and used cross-bar locking, but actuated in a different way; it wanted, however, locomotive work to make it perfect, and as he could not afford that, he had adopted the apparatus of Stevens and Sons, which had given the greatest satisfaction. With Mr. Webb's machine there were certain combinations of locking that could not be effected in the ordinary way, but that was not the case with the tappet-locking frames which Mr. Edwards had adopted. As to the question of cost, when Mr. Webb supplied the frames, he charged £5 per lever, but the apparatus to which he had referred, he should be happy to supply to the London and North-Western Company for half the money, and guarantee them for ten years. With reference to the lamp brought before the meeting by Mr. Webb, the details had been arranged by Mr. Price, of the Gas Department of the London and North-Western Railway, on the suggestion of Mr. Edwards, who introduced it. It saved the company many thousands of pounds, the amount in round figures being about £3 per lamp per annum, so that if applied to all the signal lamps on the London and North-Western Railway, the saving in cost of lighting the signals on that line would exceed £40,000 per year. This lamp was now in use on the Lancashire and Yorkshire and many other lines. Mr. Edwards.

Mr. Hodgson. Mr. Charles Hodgson observed that attention had been drawn to an invention of Mr. Saxby's in 1856, and he thought that direct evidence of the importance attached to it was to be found in the fact that, when Mr. Saxby in 1870 applied to the Privy Council for a prolongation of his patent, his application was opposed by almost all the railway companies of the kingdom. He had always been struck with the great amount of space occupied by the locking gear in Mr. Webb's apparatus. It was stated in the Paper that, in the apparatus being made for Rugby with one hundred and eighty levers, the vertical locking-bars were 18 feet deep, and the horizontal locking-bars 83 feet long. A depth of 18 feet appeared to him to be a very great space to be required for locking gear. The cabin, he supposed for that reason, was made 23 feet high. Possibly that height might be necessary for some other reason than the space required for the locking gear, but he thought it would be generally admitted that it was not desirable to have signal-cabins so high above the rails; and that it would be better to have them 8, 10, or 12 feet high, so that the signalman might be nearer the points, and have a better view of all that was surrounding him. With a cabin 8 or 10 feet high, he did not see how the Rugby locking could be fixed, because it required a depth of 18 feet, and it would be necessary to have a pit in which to place the locking, or to arrange it in some other way. But there was another difficulty that he thought would arise in the general application of such locking; he referred to the case of cabins on girders over railways, as at Cannon Street, Charing Cross, Waterloo, and other places. One instance occurred

Mr. Hodgson. to him, where the interlocking had just been completed, namely, the terminus of the Eastern Railway of France in Paris, where there was no place for a cabin but over the lines, and very little space in the cabin for the locking-gear. In such a cabin, the space available was only 3 feet 6 inches from the floor to the under-side of the girders, and the horizontal space under the floor was occupied with connections to and from the various levers. Altogether there was only a space of 3 feet 6 inches by about 1 foot in depth, in which to place the whole of the locking required of the apparatus of the type mentioned in the Paper. Of course the question of cost was involved in a heavy locking. No doubt the apparatus described was an efficient and a strong one, and the question of first cost might not always be so important as it was sometimes held to be. The great thing was to secure an efficient and reliable apparatus. The locking in the case of Rugby, with one hundred and eighty levers, might, he thought, be got into a much less space by adopting some other type of apparatus. In a frame made by Saxby and Farmer for the Brighton Station with two hundred and forty levers, all the locking was got into a space of 4 feet 6 inches by 1 foot deep. In Fig. 11 a detail was shown of the adjusting screw for the rods. The Author had drawn attention to the two small detector-holes, to enable any one to ascertain whether the rods were sufficiently far through the nuts to be secure. Mr. Hodgson thought that that was not the best type of adjusting-screw. It was, he considered, better to have an open link-shaped screw, something like the adjusting link used to couple vehicles together on a railway, so that it might be at a glance apparent that the rods were sufficiently far through the nut or otherwise. It should not be necessary to probe through the detector-holes to ascertain that important fact. An open adjusting screw was preferable. The remarks of Mr. Blackall, with reference to the periodical renewal of the connections to facing points, were, he thought, very important. In many instances the connections to points, particularly to facing points, had been allowed to be in work for such a long period that they had decayed, and serious accidents had been the result.

His name had been mentioned in connection with the interlocking of block instruments, which had been styled the union of the block and interlocking systems; and reference had been made to an accident that had happened at Arlesey, which it was said might have been prevented by the use of that union. That was no doubt the case, but at the time the accident occurred the system had not been invented, and therefore could not have been applied. Mr. Spagnoletti

Mr. Hodgson.

had described his method of interlocking the block instruments by means of the apparatus in the room, and had pointed out that his object was to prevent the signal-lever at one station being moved for lowering a starting-signal until an electric permission had been received from the next station in advance; and he had also pointed out that there was a control exercised by the passing trains to prevent the locking being taken off improperly. That was no doubt very useful as far as it went, but it was necessary to go further, because after a signalman had been allowed to pull over his lever by giving him "line clear," there was nothing in the arrangement described to make him put the lever back again. He might take his starting signal off and leave it off for a long period, and that had been frequently done. He thought, therefore, that it was necessary to go beyond the arrangement described, and to give the signalman at the advance station the power of putting the signal arm at the next station to danger after it had been lowered. That had been successfully carried out, so that in the event of the signalman omitting to put the lever home after he had lowered the semaphore, the arm was put to the danger position again by the action of the man at the advance station. But it had been necessary to go a step beyond that, because it had been said that the man who worked the signal might omit to put the lever to the danger position after he had allowed the train to pass, and the man at the advance station also might neglect the task assigned to him; and it had consequently been necessary to make the train itself so act upon the signal as to put the semaphore arm to danger in the event of the two men omitting to do so. There were, therefore, three means of putting the signal to danger—the man who worked the signal, the man at the next station, and the train itself. Further than that, when the train that was in the section came out at the other end, it unlocked the instrument there, so that permission could be given for a following train. Until the first train had come out of the section, a second could not be allowed to enter. That seemed to him to be the most secure arrangement for working the block system. There was another matter of some importance, namely, the fish-tailing of the distant arm—a small notch cut in the arm as shown in Fig. 5. It was a method devised by Mr. Williams of the Brighton line for distinguishing distant arms from home, or starting arms, and it had been of great value. The driver, on approaching an arm that had a nick in it, was aware that it was a distant signal, and not a stop-signal. It had also been found necessary to distinguish the lights at night. The home- or the distant-signal showed a red light

Mr. Hodgson. at "danger," and usually a green light for "come on," and a driver at night of course could not see a nick in the arm, so that he could not tell whether he was approaching a distant-signal or a stop-signal; and it had been found desirable that the indication given to the driver by day should also be given to him at night. That had been effected by making a hole in the side of the signal lamp, and inserting an elbow, in which there was a reflector, so as to obtain a second and smaller light without an additional burner, the small light being, say, 2 inches in diameter, and the main light 6 or 7 inches. The small subsidiary light could be changed in colour, as in the case of the main light. He thought that was very desirable, and it appeared to meet the case without additional expense. Of course it could be carried out by an additional light, but that would involve a cost of about £5 per signal per annum. The plan he had mentioned was likely to come into general use, something of the kind having been asked for by the Board of Trade. The original invention comprised in the union of the block and interlocking systems consisted in combining the block telegraph instruments in the same apparatus with the point and signal levers. The point and signal levers were made to interlock each other, and in the same way the block and telegraph instruments were made to interlock with the point and signal levers, so that there was a mechanical combination of the two systems. Prior to 1877 the two appliances were distinct, and worked independently of each other. After the serious collision at Arlesey, which resulted in the death of thirty or forty persons, it occurred to him that it would be desirable to combine the two appliances, and that had been done. The system had been extended by electrically interlocking or controlling signals from distant stations, so as to ensure that the indications to the drivers should correspond with the electrical indications that were sent to, and received from, the distant stations. It had been said that the appliances to which he had referred were hardly so necessary on long lines as on the metropolitan lines, where the traffic was very constant; but he could not agree with that remark, because he thought it had happened that trains were permitted to enter block sections, and from some cause or other stopped, and the signalman at the exit station having forgotten the first train, had permitted another to enter the section, leading to serious accidents. Whether the distance between the cabins was 5 miles or only 1 mile, the same thing might occur, and the union of the block and interlocking systems, as he had just described, entirely got over that difficulty.

Mr. Park. Mr. J. C. Park, after six years' experience of the working of Mr. Webb's apparatus, was able to endorse all that the Author had said in its favour. It had been adopted by the North London Railway Company as a standard frame, and the Company had established a department not only for manufacturing the apparatus, but for repairing and keeping all the signal work on the line in order. The greatest test to which it had been put was at Dalston Junction, where upwards of seven hundred trains passed daily, and no difficulty had been experienced in keeping the interlocking in order. It had been found to work in every way satisfactorily. With reference to an invention mentioned in the Paper, brought out by himself and his then assistant Mr. Pryce, it was called on the North London Railway a Train Protection Bar (Plate 3), and with so many trains passing over the line it was found to be very serviceable. In 1881 they supplied seven bays at Broad Street with protection bars, which controlled the home signals at the outside of the station, and also the slots on the home signals at the Junction in the rear at some distance from the station. The bar prevented the signalman in the box from taking off the signals, or in any way interfering with them when the bays were occupied by trains. The satisfactory working of the bars for two years had led to an order from the Directors to supply bars all over the line. At Dalston each bay or each six lines of railway had been supplied with protection bars, and no mishap of any kind had happened. The bars had also been placed at junctions and at ordinary stations where the home signals were controlled. The apparatus was working well, and it was a simple mechanical appliance. They were also of great value at such places where there was a junction a few hundred yards in advance of any ordinary station, where trains were sometimes kept waiting at the junction signal on the main line before entering a siding or going on to a branch line; they were then placed some distance in the rear of the junction home signals, and the wires which worked the home and starting signals of the station in the rear were led to the bar, and over guide-wheels, back to the signals; or when the signals were worked by rod, the rod had simply to be extended from the signal to the bar. He preferred the wire arrangement. This especially applied to places where, in misty weather, the signalman of the station in the rear of the train could not see the train waiting a few hundred yards in advance of him on the main line. This was how the bars were fixed at New Inn Yard Junction in advance of Shoreditch Station, and at Western Junction, Dalston, in advance of Mildmay Park Station. By this arrangement the home and

Mr. Park. starting signals of these stations were held at danger whenever a train was waiting on the main line at the junction ahead. A similar arrangement was carried out at ordinary stations where the platform was in advance of the home signal in the rear of the cabin. The wire was led from the cabin to the bar over a guide-wheel and back to the home signal. The great feature in the invention was that the signal could be put to danger even though the train had arrived on the bar first, as the bar never rose enough for the levers which carried it to reach a vertical position, and therefore it fell back into its normal position when the pawl had slipped and while the signal was being lowered; when the signal was again put to danger the pawl re-engaged in the quadrant and was locked, and however the signalman might strain the lever the wire between the bar and the signal remained dead so long as the train was on the bar. There was no limit to the number of signals that could be controlled by one bar, and it was not necessary to have separate shafts for each signal; any number of levers and pawls could be made to work on the one shaft; and further, it was not even necessary to have a lever and pawl for each signal where the ordinary locking in the box prevented more than one signal being lowered at any one time, such as where two or more lines converged immediately before entering a station. Then it was only necessary to have the one shaft and one lever and pawl with a slotted link in the wire of each signal, instead of the ordinary shackle in which the stud pins on the pawl lever could work.

Mr. Fisher. Mr. H. O. Fisher observed that he felt justified in saying, from practical experience, that the apparatus of Messrs. Mackenzie, Clunes, and Holland had given every satisfaction. Taking the number of levers on the London and North-Western Railway, as stated by Mr. Webb, the average came to about fifteen levers per mile of line. On the Taff Vale line, where the apparatus of Messrs. Mackenzie, Clunes, and Holland had been fixed, the number was twenty-six per mile of line. With reference to the question of using the Great Northern arm, it had been adopted with great success, and had been found much more economical than the old style of arm. He agreed with Mr. Blackall that the facing points were a very important element. As far back as 1876, when Mr. Fothergill, who represented Messrs. Saxby and Farmer, went down to Treforest, he pointed out to him what he considered a great weakness in their facing-point lock, namely, that if any disconnection took place between the point and the signal-cabin, the man could bolt his points, though they might lie in the wrong position for the signal given. To obviate that, the Taff Vale Railway Company decided to use two bolts and one hole in the stretcher-bar, instead of one bolt and two holes in the stretcher-bar. That had been worked since 1877, and had not given any trouble. The divided stretcher-bar was first suggested by himself, and was used on the Taff Vale Railway as far back as 1877, and he now found that Messrs. Saxby and Farmer had adopted it. With this divided stretcher two locking-bolts were used; the bolts were made to work through the passages in a block or casting, as at present; the bolts were actuated by separate levers, one bolt was connected by a rod direct from the lever to the main signal, the other to the branch signal. The connection was so contrived that the bolt was shot sufficiently to lock the points before the signal could commence lowering. Neither signal could therefore be lowered unless the points were properly set. By a simple arrangement the signal could be put back to danger without withdrawing the bolt or actuating the bar, but the bolt could not be withdrawn without lifting the bar. The Taff Vale Railway Company had also an apparatus for working the home and distant signals on the same lever. Engineers knew well that when they had an apparatus fully in use, and wanted to get a lever for an additional siding, it became an expensive matter to extend the frame; but by using the apparatus he had mentioned, it had been practicable, according to the number of distant signals, to put in so many extra sidings with but little expense. The method had been adopted upwards of two years, and had been approved by the Board of Trade. With reference to the regulations quoted in Appendix II., he thought it was a mistake not to put the junction signals at the fouling-point. It was rather an invitation to the driver to get beyond it, if it was any advantage to him to do so. He should be glad to know the Author's reason for saying that electric repeaters should be avoided as far as possible. Considering that the first cost and the cost of maintenance were so small, he had used them in every place where there was the least difficulty in the way of the signalman satisfying himself as to the working of the distant signal. Mr. Fisher.

Mr. R. C. Rapier said that when the subject was before the Institution in 1874, there were two or three points to which attention was very much directed, but they had not been alluded to in the course of the present discussion. The most striking feature of the interlocking story was the interminable number of levers, and the great quantity of apparatus, rods and wires. At the period to which he referred it was thought that one Mr. Rapier.

Mr. Rapier. hundred levers in one cabin was a large number; now, he was told that there were sometimes as many as two hundred and forty. The matter was an important one, because the amount of physical exertion which each signalman had to go through was very serious, and was, he believed, exceeded only by that of the ancient puddler. If everything that required exertion should be done, not by the labour of man, but by some of the forces of nature which it was the duty of engineers to turn to account, it was time to look to some other source of power for the working of the multitudinous apparatus of signalling, and that the signalmen should be relieved from their severe physical exertion. Not only had they severe bodily labour to undergo, but they had to keep their heads clear, even with the aid of instruments to tell them what they themselves last did, for without such instruments they could not recollect. He hoped, therefore, that he would not be considered sanguine in saying that there was a field to occupy the attention of engineers in working all switches and signals by some other force, probably electricity. He had seen some interesting appliances of Mr. Timmis, and, so far as could be judged from a single examination, there was enough in them to deserve careful consideration. At any rate, he thought all the necessary labour ought to be accomplished by means of a few powerful batteries. The subject was of more importance than might at first sight appear, because there could be no doubt that as soon as electricity was brought into use for the purpose of moving points and signals, it would also be brought into use for the purpose of interlocking one point and signal with the various other points and signals, and that could be done much more simply, and with far less cumbrous gear, than by any of the apparatus now in use. The existing forms of apparatus all did well, and one was as good as another. In 1874 many kinds of apparatus were laid before the Institution, as simple as any of those at present in use. He did not think that much was to be gained in that direction, but a good deal was still to be done on the other subject referred to, namely, giving drivers more notice. With a driver flying along with an express train at 60 or 70 miles an hour, it was not a pleasant thing to have only a mile, or even half a mile's notice, of what he was to expect in front of him. An improvement had recently been effected by placing, wherever practicable, the distant signal of one station on the same post with the starting signal of the preceding station, so that a driver about to leave station A knew that if the distant signal was also in his favour, he was not only at liberty to leave station A but proceed as far as station B.

Mr. Rapier. The difficulty of placing the distant signal of one station on the starting signal of the preceding station was, that sometimes the distance was too great to be satisfactorily worked by moving wires; but if the agent were electricity, then even if the stations were 3 or 4 miles apart, the distant signal of station B could be placed on the same post with the starting signal of station A. In this case the driver would have more notice as to the state of the road. That, he submitted, would be an important advantage; and the two subjects were so intimately interwoven that whoever succeeded in solving the one problem would also solve the other. As to the maintenance of levers, he was disappointed to find that Mr. Webb's system involved so large an annual cost. He was sure there were plenty of instances of locking apparatus on the Great Northern Railway where the maintenance had not cost 10*d.* per lever per annum. The importance of the whole subject had been well illustrated by the statement that on the Taff Vale line the number of levers amounted to twenty-six per mile of line. Under such circumstances it was quite time that the number should be reduced, or that they should be a great deal easier to handle, and that all this expense and effort should give better and more complete results.

Mr. Thompson. Mr. A. M. Thompson, in reply, said in advocating that all railways should have their signalling work superintended by an engineer specially trained for it, he regretted that the words he had used should have suggested, as they appeared to have done to Mr. Farmer, that he viewed a signal engineer as not yet created. Knowing the many valuable appliances that had been introduced in connection with railway signalling, and the many able hands that had been at work, and observing the work that had been carried on by Mr. Farmer and his partner Mr. Saxby for so many years, he could scarcely assert that a signal engineer had no existence. He should be sorry if he had intentionally done Mr. Saxby an injustice in not crediting him with being the original inventor of the locking apparatus. He had carefully examined the patent of 1856, and he could not trace in it any such clearly-defined system of interlocking as was shown in Mr. Austin Chambers' patent of 1860, and he accordingly adopted the view which appeared to prevail in the discussion on Mr. Rapier's Paper. In connection with the patent of 1856 he was astonished to hear that Mr. Farmer had claimed the invention of the mechanical slot. When the London and North-Western Company took charge of the signal work he was sent down to Shap summit, near Carlisle, to see a slot which one of the assistant

Mr. Thompson. engineers had schemed and provided on a signal. He had told him that he had not only provided the slot at Shap but also one at Carlisle and at Carnforth, where he had shown it to Mr. Saxby. Shortly after, in 1867, Mr. Saxby patented the slot; and he thought that Mr. Saxby would scarcely take the same view that Mr. Farmer had done, for he would certainly not patent a thing in 1867 if it were covered by his own patent of 1856. Mr. Farmer had referred to the catch-rod locking apparatus, and stated his opinion that this system of locking was superior in some respects to the system of lever-locking. One advantage that it was supposed to have was that the locking was actuated before any movement took place in the lever; and another was that the locking might be of a very light design. When Mr. Webb first designed the locking apparatus, illustrated in Fig. 3, it was designed as a catch-rod locking apparatus, and it was provided with an actuating piece, illustrated in Fig. 2; but after about two thousand levers had been manufactured, Mr. Webb thought that he might simplify the frame; he introduced the actuating piece shown in Fig. 3, and he made it into a lever-locking apparatus, the action of which he would endeavour to explain. When scheming the actuating piece it was provided with an adjustable centre, and having ascertained exactly the strain that was thrown on a locking bar when actuated by the catch-rod, the centre was moved up until precisely the same strain was obtained on the locking-bars when actuated by the lever as when actuated by the catch-rod; so that as far as the locking-frame was concerned, a lever-locking apparatus might be designed with locking-bars of quite as light a design as could be employed for a catch-rod locking-apparatus. It would be seen that it was almost impossible to move the lever until the actuating piece had tilted, and as a fact it tilted when the lever had made $\frac{1}{32}$ inch of its stroke. It would be understood that the actuating piece must of necessity tilt rapidly the moment any strain came on the lever. When it was remembered that a point lever had to make a movement of nearly an inch before the point it worked moved, and that a signal lever had to make a movement of 4 or 5 inches before the signal was moved, it appeared to him that there was no practical advantage in actuating the locking before the movement of the lever, and that the lever actuation system not only possessed all the advantages claimed for the catch-rod system, but possessed the advantage of having fewer parts. He thought that Mr. Farmer had done Mr. Rapier an injustice in not mentioning his name in connection with the duplex lock. No doubt Messrs. Saxby and Farmer's arrangement for working the duplex lock was a very ingenious one. It was at the Inventions Exhibition, and would be viewed with considerable interest. He had not considered it necessary to describe it, or the duplex lock designed by Mr. Webb, in which the divided stretcher-bar was employed for the first time, as the North-Western Company used neither of them. There were about sixteen hundred facing-point locks on the line, and of course it would have been a serious expense to pull them up and provide an entirely different arrangement. He did not say that the Directors would not have incurred the expense, but they were advised that by the addition of detector bars, as shown in 13A, they would secure all the advantage to be gained by the duplex bolt. He could not agree with Mr. Spagnoletti that the Signa and Telegraphic Departments should be merged. He agreed that a signal engineer should to some extent be acquainted with electricity, because he believed that electricity would sooner or later play an important part in signalling; but he thought that the Signal Department of the London and North-Western Railway Company, for example, had sufficient work for one man satisfactorily to perform. As to electric repeaters for signals he thought that they should be avoided. Where it was possible by lifting a signal 5 or 6 feet higher, to avoid an electric repeater, he thought it should be done. No matter how reliable the electric apparatus might be, it was better that the signalman should have sight of his signals, rather than that a low signal should be provided, and that he should be told how it stood by electricity. Mr. Spagnoletti had referred to the instruction that a signal, elevated more than 45 feet, should have a lower arm, and that the lamp should be fixed when practicable to the lower arm. As a rule high signals were provided in order to get a sky background, and as that was of no consequence at night, in most cases it was found suitable to place a lamp at the lower arm. Of course in some cases a high signal was required with two arms, on account of bridges and other obstructions, when it would probably be necessary to provide two lamps. The instruction was merely given to teach the inspectors not to propose two lamps when one would do. Mr. Timmis's scheme for working points and signals by electricity involved a change of very great magnitude, and would entirely revolutionize the present system, but he thought that the question was one well worthy of consideration. He was not prepared to give any opinion as to the amount of encouragement Mr. Timmis was likely to receive from railway managers, but he hoped Mr. Thompson.

Mr. Thompson. that he would be successful. Mr. Edwards was well acquainted with the working of the company's locking-frames, and knew that a hot-water heating-apparatus was not provided on account of the delicacy of the frame. It was an economical and efficient method of heating a large cabin, and as it kept the bottom portion of the cabin free from damp, any type of locking-frame was consequently kept in a better condition for work. Many of Mr. Webb's small frames had for years been working in pits entirely unprotected, and no difficulty had been experienced in keeping them in order. Mr. Webb's foreman of the Gas Department had schemed the petroleum lamp which had been exhibited, in the first instance, and it was tested for six or eight months and found to be thoroughly unreliable. Mr. Webb, hearing of the matter, sent for the foreman and requested him to bring one of the lamps, which he did. Mr. Webb said, "The construction is entirely wrong; you must provide a deflector plate over the oil cistern, an air inlet at the bottom of the casing, and an air-passage through the centre of the cistern to keep it cool." That was done and the lamp proved a complete success. The lamp shown to the Institution was practically the same as that which Mr. Webb's foreman was instructed to make. Mr. Hodgson had referred to the great length of the locking-bars required in carrying out Mr. Webb's system, and suggested that the height of the cabin would have to be objectionably great to make room for the deep vertical bars. This was not so. The London and North-Western Company had built, since the locking-frame in question was introduced, five hundred and sixty signal-cabins, and in no instance had a cabin to be increased in height on account of the locking-frame. There was always ample room in the bottom portion of a cabin to erect the locking-frame, and it was far better it should be so fixed when a fitter had ample room to work without interfering with the signalman's duties, rather than that it should be unnecessarily cramped and fixed where a fitter could not work with freedom. Mr. Hodgson also anticipated a difficulty in erecting the frame in a cabin carried on girders over the line. A large number of such cabins had been erected, and the locking-frame was precisely the same; but instead of its being placed below the quadrants, it was placed behind the levers, a short compensating lever being provided to transmit the motion of the actuating piece. As regarded the cost of new works, he was surprised that Mr. Edwards should admit that the work carried out when he was the company's superintendent should have been so costly, but, fortunately for his credit, the figures he gave were

Mr. Thompson. incorrect. The average cost of the work carried out during Mr. Edwards' term of office was 38 per cent. less than the average cost of work done by contract at the time the Company took the work into their own hands, and it was reasonable to say that such a result was inevitable, considering the perfect appliances the Company possessed at Crewe for the economical production of the standard work, appliances a contractor could not as a rule adopt, on account of the different types he must make to suit his customers. There appeared to be some misunderstanding as regarded the cost of maintenance. The average annual cost was £38,500, which, divided by the number of levers in use on the line, twenty-six thousand five hundred, came to £1 9*s.* per lever. This amount included not only the renewal and repair of the locking apparatus, but the signal cabins, signals, and all subsidiary apparatus, and also the cost of providing any new and additional apparatus when under £10. The amount of work to be maintained had increased 80 per cent. since the year 1874; the cost of maintenance had, however, only increased 5½ per cent., an unanswerable argument in favour of the London and North-Western Company's practice.

Correspondence.

Mr. Hamilton-Smythe.

Mr. A. J. Hamilton-Smythe differed from the Author as to the art of Railway Signalling necessarily becoming a special branch of engineering, and thought it doubtful if it would prove a good arrangement on railways generally to make the erection and maintenance of signal-apparatus independent of the permanent-way department. He considered the duties and responsibilities of the men who laid in and maintained the points were too closely interwoven with those of the men who fitted up and maintained the apparatus working the points, for it to be desirable that each staff should be under different departmental chiefs. He corroborated what the Author had stated as to the importance of uniformity in signalling, and the delay and expense in effecting repairs or carrying out alterations on lines where several different types of locking apparatus and signal fittings had been introduced. The course adopted by some railway boards of throwing open to competition the contracts for interlocking separate stations with the system of fittings represented by the successful contractor was regrettable, and would prove very uneconomical. He knew of one small railway on which, despite the previous protest of the engineer in charge of the district including it, there had been no less than six different systems of interlocking divided among ten recently interlocked stations, with the result that the cost of signal maintenance was, and must continue to be, unnecessarily great. Railway companies that did not manufacture their own signal-apparatus should, in his opinion, invite tenders for supplying all signal-fittings to uniform standard patterns at scheduled prices, and the lowest tender should not be accepted without careful regard to the system of locking and patterns of fittings to be supplied. The delay and confusion in replacing broken castings, or other fittings, on lines where a number of different types were in use was excessive. Engine-drivers were often timed and required to run at full speed past signals showing green caution lights, and he thought the use of any signals not meant to be strictly obeyed was a dangerous sham, tending to relax the habit of scrupulous and prompt obedience to signals which was so essential. It had been suggested that green might be reserved for use in back-light spectacles only, thereby distinguishing these from train signals; but he thought green might be better used as a substitute for red in the lights of distant signals. Distant-signals served in reality merely as

Mr. Hamilton-Smythe.

indicators, or repeaters, of the signal shown by the home signal, and a distant-signal at danger was simply a direction to the driver to slacken speed sufficiently to enable him to stop before reaching the home signal. It seemed very desirable, not only that distant-signal lights should be clearly distinguishable from home-signal lights, but that red lights should be reserved for stop signals only; so that when a driver saw a red light he should be in no uncertainty as to whether he should endeavour to stop or not before reaching it. He agreed with the Author that the working of facing points and their bolt-locks by the same lever was objectionable for the reasons given in the Paper, and he had found that when both ends of a cross-over road, one end of which was bolt-locked, were worked together with the lock by one lever the pull was too heavy.

Mr. Johnson.

Mr. HENRY JOHNSON observed that many companies were in the position occupied by the London and North-Western Railway Company before the Directors decided to appoint a Signalling-Engineer, and were largely dependent on contractors for the proper execution of this work. A signal-department was an urgent need on every line of importance not possessing one; and although it was debatable whether or not it was desirable that railway companies should carry out their new works, or let them to contractors, there could be no doubt that a large saving was effected by such work being carried out under proper supervision by competent persons, acting solely in the interests of the companies. The economical carrying-out of repairs and alterations depended upon such a department, as well as the maintenance of work in a safe condition. The time was not "shortly to arrive," but had long since arrived, when this branch of railway engineering ought to be managed by duly-qualified signalling-engineers, both in the interests of shareholders and the public.

In admitting that an improvement had taken place in the signalling on the London and North-Western Railway since the work had been done by a properly organized department, he did not necessarily assent to the reason assigned, namely, that the Company's engineer had become, through being afforded greater facilities, better qualified as a signal engineer than those who had received their training as contractors. Probably improvement lay chiefly in administration, and in consequence of the department possessing powers of control and direction that could never be obtained by a contractor.

He was somewhat disappointed that no mention had been made of the progress effected since 1874 in special locking. It would

Mr. Johnson. have been interesting to learn what were the various mechanical contrivances employed on the London and North-Western Railway in carrying out such requirements, because this matter entered to a certain extent into the consideration of the question of the best locking apparatus. Unless the ordinary locking employed admitted of being adapted to the special requirements, it became necessary to examine the principles of the special contrivances before a satisfactory conclusion could be arrived at. Messrs. Stevens and Son's locking-frame was, he believed, the only machine in which one principle of locking was maintained throughout, for special as well as for ordinary locking; it possessed several admirable features, and was better in practical utility and economy, though perhaps not in appearance, than any other frame extant, constructed as it now was by the Cheshire Lines Committee, namely, with locks arranged for steps, so as to be easily got at for examination.

There must be pretty general concurrence with the Author's remarks under the head of signals, but some interesting information was missing. No mention had been made of signalling in foggy weather. This was a subject of high interest to railway men. He inferred that the old system was continued of placing fog-men out, with detonators; but this system was very expensive, and unsatisfactory. This work was generally done by the permanent-way staff; and to shield that department from blame, in case an accident occurred through a driver's negligence, when a slight fog existed, men were sent out at times when signals could very well be seen. He had many times taken especial notice during fog, and had found that it must be very dense indeed before a driver's view of the signals was materially affected by it; but in the absence of a detonator, or something as a substitute, the presence of a fog created a loophole of escape from blame for those in charge of a train incurring an accident on such an occasion. Many appliances had been devised for placing detonators on the rails, and causing audible and visual signals to be operated on the engine, by the signalman, when the distant-signal was at danger, and a fog existed; but as a rule these inventions were made by persons practically unacquainted with the subject, and would introduce a fresh element of danger. A middle course appeared to be desirable, namely, something to indicate to trainmen that they were approaching a distant-signal, and at the time of receiving the indication were within a certain stated distance from such signal. This would perhaps be best effected by an apparatus fitted to the engine, and operated by some fixed block, Mr. Johnson.

or incline, on the railway. Any parts liable to derangement would thus be on the engine, and under the constant care of the driver. It could also be made to move in and out of gear, so as to be used only when the driver needed it to assist his vision. The instructions to the train-men would be, that in the event of not being able to see the signal, they must treat it as "danger," and proceed accordingly. In fact, the rule in general use, which provided that in the absence of a signal, where a signal should be, the driver must proceed as for "danger" would here be sufficient. This arrangement would not only serve to obviate the necessity for sending out men, except when very dense fogs existed, and even in their absence securing safety, but would render practicable the rule above referred to, which was not so at present, for if the driver's memory failed to fix where an absent signal should be, it was impossible for him to obey the rule.

He did not understand why any distinction was made, in point of importance, between one station and another, or between a fouling at a junction, and a fouling at a siding. Accidents might occur at any point where signals were disobeyed, and very serious ones had in fact occurred, at what might be considered unimportant stations, such, for instance, as those at Abbot's Ripton and Brierfield. Hence, it seemed an unnecessary anomaly to provide "caution" signals at one place, and "all right" signals at another. Many companies had abandoned the "caution" signal, and appeared consistent in so doing. Had not the Great Northern Railway Company adopted the green light as an "all right" signal, and had all other companies adopted the "all right" system throughout, the green light would have been set free for another and useful purpose, namely, to distinguish by night distant from home signals; the green light being used for danger on home and starting signals, and the red light being retained as a danger signal for distant signals. That a distinction was considered desirable was evident, since all companies had adopted a different shape from all others for distant signal-arms, but this was only of use by daylight. Since the distant signal was the one which checked drivers when the train was going at top-speed, and since the red light was seen more distinctly than green, the former was more suitable for that signal.

A practice had of late years sprung up on some lines, the London and North-Western amongst them, of placing as many distant signals as there were home ones, for traffic approaching points of divergence; but it was not in all cases, where adopted, uniformly carried out. It would appear better to use the system

Mr. Johnson. entirely, or not at all; but it multiplied signals so much at complicated junctions, that unless a good case could be made out in favour of its general adoption, it would be better abandoned. He was of opinion that a sufficiently strong case could not be made out to warrant its adoption.

There was one exceedingly weak point in relation to the use of distant-signals which ought to be remedied, namely, the insufficient protection afforded by them in short sections. The distant-signal was usually placed on the home-signal of another section; an indicator was placed in the sight of the operator, and he was instructed by rule to keep his distant-signal at danger as long as the indicator showed the danger position. This was not only inconvenient, but unsafe, because it relied, not upon the interlocking for safety, but upon independent human agency. This danger was avoided where what were known as disengagers, which practically acted as slots, or slots themselves, were used, giving the operator of the distant-signal control also of the adjacent one; but the great inconvenience and disadvantage remained, of the distant-signal being at too great a distance from the home one. The inconvenience of the present system might be illustrated by describing its working of the system, where a number of short seotions joined each other. Supposing there were ten short sections of about 500 yards, each lettered A to J. Take the movement of trains from J to A. The line was fouled at section A, and the other sections were clear, but the distant-signal at J was kept at danger to protect the section A, at a distance of nearly 3 miles. All sections should have distant-signals placed at proper intervals from their respective home-signals; and where they overlapped the home-signal of another section, the distant-signal should be repeated on that home-signal. By this arrangement, train-men would not be led to treat distant-signals lightly, as where they were thrown out some miles from the actual point of danger, to say nothing of the saving of time that would be effected by the change.

There appeared to be a great want of precision in fixing the positions of distant-signals. These signals, now that the block system had been generally adopted, served only the important purpose of giving timely notice to train-men that they were required to stop at a position determined by the home-signal. All rules that fastened responsibility on train-men for running into anything between the home- and the distant-signals, by laying down that they must be prepared to stop at distant-signals, under the block system, when at danger, were impracticable, because traffic could not be worked, and the rules obeyed. A rule holding drivers responsible for a constant, vigilant outlook ahead was justifiable, and sufficient. Taking the distant-signal to stand for the object named, where was the consistency of the London and North-Western Company's instructions to inspectors under this head? The 1,000 yards was a distance fixed on the level, and the same for falling gradients, except in "special cases," when the distance might be extended to 1,200 yards. This was a very indefinite instruction. The maximum distance for falling gradients was 1,200, and the minimum for rising gradients 800. Should not these distances be regulated relatively by the power of the driver to stop the train on the respective gradients? In this case is not 800 yards much too high a minimum? A table of distances, regulated by the gradient, seemed to be much required. Mr. Johnson.

A little more information with respect to signalling sidings would have been serviceable. The system, in use on most lines, of giving a signal for departing out of a siding, having a long shunting neck beyond the outlet crossing, but no signal for entering the neck, made it necessary for drivers to pass the one signal at danger, and led to the disobedience of siding signals generally. Several accidents had been traceable to this arrangement. A driver with an empty engine, on a very dark night, moved past the siding signal at danger, supposing that he was moving to the neck; but the crossing outlet of the siding not having been closed until after he made the movement, he stood upon the crossing, and fouled the main line. The main line train was signalled, and the engine was run into by it. To obviate this state of things he had brought out a simple siding signal, with two or more arms and lights; it was worked by one lever, the position of the points determining which arm was to be lowered. This signal had been used considerably by the Lancashire and Yorkshire Railway Company.

Signal slots were evidently named from their original construction, when perhaps it would have been more appropriate to have named them from the purposes they were intended to accomplish. One firm gave the apparatus, differently constructed, the name "Co-acting apparatus;" but the name "slot" had become more general. Various means were employed for jointly controlling signals, but none were perfectly satisfactory. All those that lowered the arm by weight, instead of by force, did away with the advantages of a balanced arm. Messrs. Saxby and Farmer used one that lowered the arm by force; this caused the operator's pull to be variable, the pull being heaviest to the last operator.

Mr. Johnson. There was also loss of stroke under some circumstances; for instance, suppose a signal to be controlled by three men, and each man only made two-thirds of a complete stroke, the arm would remain at danger, because the sum of the deficiencies was equal to one stroke; or, in other words, three complete strokes were required to lower the signal, the two first going for nothing until the third took place; and as only two out of three were completed by the three operators, the arm remained at danger when it should be lowered. The objections to the first description of slot were, however, the gravest, because attended by the risk of a breakage lowering the signal. Slotting was not, therefore, at present desirable where it could be avoided. It was very necessary that distant signals in close proximity to a home or starting signal should continue to be slotted; but in almost every other case they might well be dispensed with, as there was seldom any advantage in making one set of signals answer for two concentrations of points.

It would be interesting to know the Author's reasons for the opinion that the best position for a compensator was at the signal-post. Too much was expected from a compensator. Signals were often hard to work, apart from the question of adjustment; but where a compensator was inserted it was expected to overcome all sorts of difficulties, quite foreign to its purpose. Experts had experienced the greatest trouble in making some signals work anything like satisfactorily, and there were signals that never had worked well. This, no doubt, arose from extreme lengths, and complicated routes of connections. Improvement was needed here, so that the lever pulled over slowly should lower the arm to its off position, before the stroke of the lever was quite completed, and on putting the lever back slowly, the arm should resume the danger position, before the lever was quite back. Improvement lay probably in adopting the lightest possible connection. Any signal so put to work would continue to work accurately, whatever the changes of temperature might be, by the insertion of a Johnson's liquid compensator. The accurate working of signals was a matter deserving more attention than it received. Signals generally acted unsatisfactorily, so much so, that if drivers were to obey the rules, and accept only proper "all right" signals as "all right," there would be a dead-lock in the working of traffic. If signals could not be worked accurately by mechanical means, it would perhaps be better to give a thorough trial, on an extensive scale, to the best electrical contrivances.

The comparison between the channel and pipe sections of point connections was somewhat over-strained. Given a pipe-section of the same weight and quality of metal as the channel section in use, the former would no doubt be stronger and as durable as the latter, and be less liable to corrosion on the outside, owing to its more readily throwing off moisture. It was questionable whether corrosion went on inside to any important extent. If the channel section possessed an advantage, it lay in the facility it presented for jointing securely, but this was doubtful. The joint used by Messrs. McKenzie, Clunes, and Holland for pipe-section consisted of solid ends and a socket or collar. These were screwed and tapped deeply, by a process which thoroughly tested and detected any defects in the ends operated on; and, the strain upon them then being greatly in excess of anything they subsequently had to bear, should give a thoroughly trustworthy joint. Such was the case; not a single failure had occurred in these joints. In comparing the durability of the sections, they should be subjected to the same conditions, and this had not been done. The failures of pipe-sections, through corrosion, that had come under his notice, had occurred through neglect of proper inspection and maintenance. The channel section had not been subject to such neglect. Again, the quality of the material in the channel section had not been subject to the deteriorating influence of severe competition, without adequate measures for securing good quality as in the other case. Assuming that the pipe-section proved to be as trustworthy as the channel section, and not more costly, many persons would no doubt prefer it as possessing a better appearance, and as needing less frequent painting. **Mr. Johnson**

As accidents were liable to occur at the most out-of-the-way places, all junctions through which passenger trains ran ought, he thought, to be considered of equal importance, in respect of being fitted with safety appliances. A simple and cheap contrivance was now being exhibited at the Inventions Exhibition by the Johnson's Compensator Company, consisting of two spiral springs, by which the switches were forced from both stock rails, in the case of a failure in the connections. This prevented the facing-point lock being worked and the signals being lowered, and drew the signalman's attention to the defect at the facing-points. The arrangement could be fitted to a set of facing-points in a few minutes.

The train-protection bar of Messrs. Park and Pryce was a useful invention, applied to the purposes named by the Author; but railway companies should guard against its employment in unsuitable ways. He had seen single ones fixed in long bays, Mr. Johnson. leaving it possible for an engine to stand in several dangerous positions in such bays, and the ingoing signals free to be lowered. This was unsatisfactory and an unnecessary outlay; it did not secure safety, and might lead the signalman into misplaced confidence. It had also been adopted in some instances where ordinary locking bars would have served the same purpose.

The Author had rendered railway companies a great service in his remarks on locks for outlying sidings. One or two stations on the Midland Great Western Railway of Ireland had been partially fitted up some years ago in the manner described, and met with the approval of the Board of Trade, owing principally, no doubt, to the fact that the points so treated were not within a reasonable working distance of the station, but partly because the sidings were not frequently used. That such an arrangement did not accord with the Board of Trade regulations, was to be regretted, because it blocked the way to economy, where it was much needed. The system, however, if not very carefully applied, might lead to delays, and consequently, indirectly, to danger. Companies would be tempted to adopt it, for the sake of economy, where traffic would scarcely admit of the delay it undoubtedly introduced, and would also be slow in substituting concentrating apparatus for it when traffic had improved. The Board of Trade would therefore, no doubt, in altering the regulation, retain the authority to say where it might be introduced, and take powers to order its abandonment, after the traffic had increased to such an extent as to render the system unsuitable.

Mr. Langdon. Mr. W. LANGDON remarked that on the Midland Railway, a new form of signal was being introduced, which possessed certain advantages, the arm being so constructed that it should fall to "danger" should it, by any means, become detached. The arm also carried the spectacles as an integral part of it, so that the position of the arm would in all cases coincide with the position of the spectacles. Not many disk signals were now left upon the Midland Railway. He should be glad to learn why, under the Instructions to Inspectors with reference to signals, it was thought desirable "electrical repeaters should be avoided, even at the expense of higher signals." It had always appeared to him, and the fact that repeaters were used to a great extent upon most railways would seem to support the opinion, that they were most desirable adjuncts to the signalling arrangements. He doubted whether the raising of the signal to any elevation, however great, would quite meet the difficulties which the electrical repeater was calculated to contest. In foggy

Mr. Langdon.

weather the signals should, he thought, be brought as near to the engine-driver's eye as possible, for the reason that the farther the distance from that point, the more difficult it was to see the signal. Where electric repeaters were employed this might be done, a position being selected for the distant signal most convenient for that purpose, irrespective of the sighting of the signal from the signal box. Where a signal could be placed so as to secure both these objects, namely, the readiest possible sight by the engine-driver in all conditions of weather, and also a sight of the same by the man working the signal, it was needless to say that such a position was the most desirable; but when this could not be obtained, it seemed to him that the first point for consideration was the sighting of the signal by the engine-driver. On the Midland Railway there were more than twelve hundred repeaters, and more than six hundred light indicators in operation in connection with distant and other signals. He thought that the day was not distant when, in order to obtain a more accurate knowledge of the working of distant-signals in foggy weather, snow-storms, &c., it would be found desirable to electrically repeat the position of every distant-signal.

Mr. Price-Williams.

Mr. R. Price-Williams thought it much to be regretted that no information had been afforded in the Paper in regard to signal lamps, those now in use being, as was well known, lamentably deficient in illuminating power, and giving a very feeble light during the most favourable state of the atmosphere, and when at all unfavourable for the transmission of light, as in foggy weather, affording to the engine-driver a most inefficient and untrustworthy guide. The burner now usually adopted on railways for signalling purposes had a flat wick and was supplied either with colza, rape oil, or petroleum; there was no glass chimney, and the flame could not possibly be either high in its intensity, or perfect and economical in its combustion. It was scarcely credible that at the present time such poor flames should be used for a purpose so vitally affecting the safety of the working of railway traffic, and that the principles of the great discovery of Argand of the glass chimney and double air current—now exactly a century old—should be so entirely ignored. During the discussion on Mr. Rapier's Paper on the Fixed Signals of Railways, Mr., now Sir, James Douglass drew attention to this important subject,[1] and submitted a design for an improved railway signal-lamp, which would afford at least ten times greater illuminating power with

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[1] Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 237.

Mr. Price-Williams. the same consumption of oil, but up to the present time the old flat wick lamps had continued in use, and no appreciable improvement had been effected. The intensity of the ordinary flat flamed signal lamps did not exceed from five to six candles, while with the same dimensions Argand mineral-oil flames of ten times this intensity were now produced for coast signalling. From his observations on the working of Sir James Douglass' system of lighthouse illumination at the South Foreland and elsewhere, he was satisfied there was practically no difficulty in applying the same principles of illumination to railway-signal lamps.

It was impossible to over-estimate the importance of obtaining anything like this large increase in the illuminating power of railway-signal lamps, say for instance in the case of the distant-signals of an intermediate station at which fast or express trains did not stop; but where, as was constantly happening under cover of them, slow and heavy goods or mineral trains had to be shunted out of the way, the record of railway accidents which had occurred at stations of this kind through the engine-driver's failing to discover the distant-signal lights on thick and foggy nights, and through other causes, was an appalling one, and it was not too much to say that had the illuminating power of the lamp been only doubled, most of these accidents would never have occurred. Another fruitful cause of railway accident was the lamp being blown out by the wind; and as a preventative he would strongly recommend the simple and effective wind guard devised by Sir James Douglass, which he had recently seen in operation at the South Foreland experimental lighthouses under the most trying circumstances.

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12 May, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President,
in the Chair.

Field-Marshal H.R.H. the Duke of Cambridge, K.G., was elected by acclamation an Honorary Member.

The discussion upon the Paper on "The Signalling of the London and North-Western Railway," by Mr. A. Moore Thompson, occupied the whole evening.

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19 May, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

George Neill Abernethy.
Richard Ernest Brounger.
Francis Joseph Edward Spring.

The following Candidates have been admitted as

Students.

Oliver Elliot Bensley.
William Arthur Saunders Benson.
Ernest Walrond Bryant.
Edwin Friend Bunyar.
Henry Lowthian Cleaver.
James Croyle, Jun.
William Brown Dixon.
Robert Richard Gales.
Ernest Talbot Cope Garland.
Arthur John Lund Grimes.
Arthur Hindle.
George Frederick Glass Hooper.
Frederick Thomas Hopkinson.
Walter Robert Lewis.
Matthew Loam.
Alfred Pearce.
Thomas Pritchard.
William Wade Fitzherbert Pullen.
William Mathew Savours.
Joseph Eaves Swindlehurst.
Henry Joseph Thomas Thomas.
Edward Thompson Ward.
Herbert Nicol Weldon.
Reginald Wissenden.

The following Candidates have been balloted for and duly elected as

Members.

George Augustus d'Auvergne Anley.
Jean-Baptiste Louis Felix Marc Berrier-Fontaine.
Morris Birkbeck.
David McMordie, B.E.
Augustus Oswald Schenk.
James Thomas Simpson.
Frederick Henry Trevithick.
Arthur Tannet Walker.

Associate Members.

Herbert William Anderson.
Russell Gardener Austin.
John Thomas Prichard Bassett, Stud. Inst. C.E.
Thomas Hudson Beare, B.A., B.Sc., Stud. Inst. C.E.
Howard Brunlees.
Robert Crossley Bullough.
Arthur Hazeldein Burt.
Joseph Eden.
William Elliot, Jun.
John Tipping Gardner, Stud. Inst. C.E.
Walter Horatio Greathead.
Henry Herbert Hellins, Stud. Inst. C.E.

Associate Members—continued.

Thomas Hind Blumer Heslop.
Charles James Jackaman, Stud. Inst. C.E.
Frederick William Lacey.
Frederick Mackinlay, Stud. Inst. C.E.
William MacLeod Mackinnon, Stud. Inst. C.E.
Pedro Tomas-y-Martin.
Frederick William Maunsell, B.A.
James Munce.
Bernardo Gavião Pereira Pinto.
Manoel Eugenio do Prado.
Oliver Claude Robson.
Horace Hassall Roden.
Leonard Sartoris.
Edward Shaw, Wh. Sc., Stud. Inst. C.E.
Ayres Pompeio Carvalho de Souza.
Henry Taylor.
William Warren.
Guilherme Benjamin Weinschenk.
John Henry Richard Whinfield.
William Lawrence Williams.
Edgar Worthington, B.Sc.

Associates.

William Birt.
John Dixon.
Eardley Maitland, *Colonel, R.A.*
Richard Speight.

(*Paper No. 2070.—Abstract.*)

"On the Theory of the Indicator and the Errors in Indicator Diagrams."[1]

By Professor Osborne Reynolds, M.A., LL.D., F.R.S., M. Inst. C.E.

The object of this Paper was to define the causes and extent of the disturbances in indicator diagrams. The theory, as given, had been taught for several years in Owens College; but the publication had been deferred to enable an extensive series of experiments to be made. These experiments had now been carried out by Mr. A. W. Brightmore, Stud. Inst. C.E., late Berkeley Fellow in Owens College. In the first place it was shown that there were five principal causes of disturbance, namely, the inertia of the piston of the indicator and its attached weights; the friction of the pencil on the paper, and its attached mechanism; varying action of the spring; inertia of the drum; friction of the drum.

The effect of the inertia of the pencil and its attached mechanism presented a mathematical problem, by the solution of which it was shown that there were two disturbances from this cause;

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[1] This communication is given in abstract only, inasmuch as no discussion was taken upon it, and a complementary Paper, by Mr. A. W. Brightmore, Stud. Inst. C.E., was not read. It will appear in full in vol. lxxxiii. of the Minutes of Proceedings, and, together with the Paper by Mr. Brightmore, will form the subject for discussion at the opening meeting of the Session 1885-86.—Sec. Inst. C.E.

one, a general enlargement of the mean indicated pressure, depending on the weight of the moving parts of the indicator, the stiffness of the spring, and the square of the speed. The other disturbance was a vibration of the pencil. Every indicator piston vibrated when disturbed, so that the period of vibration depended on the stiffness of the spring.

The error which these oscillations caused in the area of the diagram depended on their magnitude, and, to a greater extent, on the smallness of the number in a revolution. But the evil of these oscillations was not so much an effect on the area as in the disfigurement and the confusion they produced in the diagram. So long as there were thirty of these oscillations in a cycle, the necessary fluid friction of the indicator piston would so far reduce them as to render a fair diagram possible, but when the number was as low as ten it was all the pencil could do to prevent them upsetting the diagram.

The friction arising from the pressure of the pencil always acted to oppose the motion of the pencil, and therefore rendered it too large during expansion and exhaust, and too small during compression and admission, and thus the general effect was to increase the size of the diagram. This friction consisted of that of the pencil on the paper; and that of the mechanism, caused by sustaining the pressure of the pencil. The effect of the friction of the pencil was greatly reduced by the motion of the paper. The magnitude of these effects taken together on the area of the diagram depended on the construction of the instrument and on pencil-pressure. From numerous experiments it would appear possible to make a difference of as much as 5 per cent. in a locomotive in mid-gear by pencil-friction.

The conclusions, as regarded the motions of the pencil, were that the general effect of inertia and friction were both to increase the size of the diagram; that so long as the speeds were such that the number of vibrations of the pencil during a revolution of the engine was not greater than fifteen, the effect of inertia was less than 1 per cent., but that if the number was greater than thirty, oscillations would show themselves unless the pencil-friction was increased. They might, by this, be kept down till the number of vibrations was equal to fifteen, but not farther, and then the necessary friction would affect the area of the diagram about 5 per cent. For the diagrams to be sensibly accurate and free from oscillation, the speeds must not be greater than would make the number of vibrations equal to thirty. These speeds were given in the Paper for Richards' indicators.

The effect of the inertia of the drum with an elastic cord was shown to be a nearly uniform elongation of the diagram. The result of the varying stiffness of the drum-spring was a nearly uniform contraction. With Richards' indicator these two latter disturbances neutralized each other at a speed of one hundred and fifty revolutions per minute. At other speeds the effects were apparent in the length of the diagram; but except when the expansion was great and the connecting-rod short, they did not affect the indicated pressure. The friction of the drum with an elastic cord caused the cord to be longer during the forward stroke than during the backward stroke, so that the diagram was distorted and shortened, the drum being uniformly behind its proper position during the forward stroke, and before its position during the backward stroke. This distortion diminished the area of the diagram according to the rate of expansion and the length and elasticity of the cord used. This was definitely expressed by a formula. This disturbance, the influence of which was very great in cases of high expansion, large engines, and ordinary cords, appeared to have been unnoticed. The circumstances on which it depended were the elasticity of the cord and the friction of the drum, and the question was how far these existed in the ordinary indicators. It might be said that the diagrams which led to the discovery of this effect were taken with an indicator which had been in constant use for several years. It was in apparently perfect condition, and the diagrams did not differ essentially from those which had been previously taken. The cord was one which had been supplied by the maker. The manner of the discovery was described: For years the Author had pursued in the class the method of testing the vibrations of the indicator pencil by projecting them on to the crank-circle, and he had noticed that the first oscillation fell short, and shorter in the back diagram than in the front. The cause of this was not obvious, and it was partly with a view to determine this cause that Mr. Brightmore's investigation was commenced. A slight error in the reducing-rod, which had a fixed centre and a slot in which a stud in the slide-block worked, was altered. This, however, did not get rid of the effect. A new cord was substituted for the old one, and the effect was found to be much enhanced, the new cord being more elastic than the old one. This reduced it to the stretching of the cord, but it was only after carefully working out the effect of the inertia of the drum, and it was seen this was to lengthen the first oscillation at the back end that the friction was examined. The indicator was taken to pieces, cleaned, and oiled;

then the effect was much reduced. Several new wires and cords were used, and eventually steel wire was adopted as the best. The test supplied by the oscillations could only be applied to diagrams taken at high speeds, and the test furnished by the influence upon area was vague. What was wanted was an independent means of determining the simultaneous positions of the drum and the engine-piston. As the best method of meeting this, it was decided to arrange an electric circuit through the pencil to the drum, with sufficient electromotive force to prick the paper, making the engine-piston close this circuit at eleven definite equidistant points in the motion backwards and forwards. This was successfully carried out, and the stretching of the cord during the backward and forward strokes was definitely ascertained. Taking the smallest results obtained with a cord, it appeared from these experiments that the least difference of stretching was to make this difference in inches 5 per cent. of the length of the cord in feet. Examples of this effect in diminishing the mean indicated pressure were given. Thus, in a locomotive cutting off at one-quarter it was 8 per cent.; in a condensing engine having 3·5 feet stroke, cutting off at one-tenth, 20 per cent.; and the same compounded, 10 per cent.

These would seem to be the smallest results that could have occurred in ordinary practice. The conclusion, however, that hitherto the normal indicated power from engines had been from 10 to 20 per cent. too small must wait for verification. Yet there were not wanting independent evidences of such an effect. In diagrams taken from engines at high speeds the admission line would not but for this effect be vertical. It would show a certain amount of detail, and the first oscillation would not have a sharp top. Moreover, it was commonly found that the expansion line, allowing for clearance, was above the true expansion line for the steam. This apparent rise in the curve of expansion was exactly what would result if the apparent cut-off was too early, and this was the result of the effect that had been considered. The Author had tried several diagrams, and found that after correction the expansion line came out very close to the true curve.

In making these comparisons the explanation of another feature of diagrams became apparent. When the two diagrams were traced on the same card, there was sometimes a want of symmetry about them, and in this case the cut-off was shorter on the back than on the front diagram. This the Author attributed to the friction of the drum when the cord for the back diagram was longer than that for the front. When this was the case, the relative lengths of the cord were about 1 to 1·8. These observations were illustrated in a diagram from "Richards' Indicator." To test this diagram a tracing was taken, and reversed so that the front diagram was superimposed on the back. It was observed that the diagrams were of different lengths, and the difference was about the same as the difference in cut-off; that, notwithstanding the apparent cut-off in the back diagram was to that in the front in the ratio of 2 to 3, the expansion line of the back diagram was the same shape as that in the front; and that if the diagrams were restored, supposing the lengths of the cords used to have been 5 feet and 9 feet, the diagrams became exactly similar, and, allowing 2 per cent. clearance, the expansion line came to be the true expansion line for that cut-off. The mean pressure was 14 per cent. larger than from the original diagram.

Such instances as these seemed to sufficiently establish a case against the blind faith which appeared to be at present placed in the accuracy of the indicator diagrams. But in conclusion the Author stated that he should be very disappointed if anything in this investigation should have the effect of diminishing reliance on the indicator itself. He would have the instrument treated fairly, and instead of being the object of unthinking worship, he would have it the object of careful study and experimental investigation, so that the limits of its wonderful perfection might be known exactly, and that reliance placed on it which sprang from knowledge.

ANNUAL GENERAL MEETING.

2 June, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President,
in the Chair.

The notice convening the meeting having been read,

Messrs. A. T. Atchison, T. H. Blakesley, G. Chatterton, F. S. Courtney, W. S. Crimp, W. A. Dawson, G. L. Eyles, A. Fyson, H. G. Harris, E. Perrett, H. S. Ridings, and T. M. Smith, were requested to act as Scrutineers for the election of the President, Vice-Presidents, and other Members of the Council for the ensuing year; and it was resolved that the Balloting lists should be sent to the Scrutineers for examination at intervals.

The Ballot having been declared open, the Secretary read the Report of the Council upon the proceedings of the Institution since the last Annual General Meeting, and upon its general condition.

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings" in the usual manner.

Resolved,—That the best thanks of the Meeting be accorded to the Vice-Presidents and other Members of Council, for the time and trouble they have bestowed in promoting the objects of the Society.

Mr. Edward Woods, Vice-President, returned thanks.

Resolved unanimously,—That the hearty thanks of the members be tendered to Sir Frederick J. Bramwell, President, F.R.S., for the great attention he has paid to the duties of his office, and for the manner in which he has devoted himself to the interests of the Institution.

Sir Frederick J. Bramwell, F.R.S., President, returned thanks.

Resolved,—That the members of the Institution desire to record the sense of their indebtedness to each of the Lecturers on "The Theory and Practice of Hydro-Mechanics."

Professor W. C. Unwin, B.Sc., returned thanks.

Resolved,—That this meeting offers its hearty acknowledgments to Messrs. B. Baker and J. Wolfe Barry for their valuable Papers descriptive of the works of the Metropolitan and the Metropolitan District Railways.

Mr. J. Wolfe Barry returned thanks.

Resolved,—That the thanks of the Institution be presented to Messrs. Edward Bazalgette and Hilary Bauerman, the Auditors, for the careful manner in which they have examined and audited the accounts; and that Messrs. H. Bauerman and H. G. Harris be requested to act as Auditors for the ensuing year.

Mr. Edward Bazalgette returned thanks.

Resolved,—That the thanks of the members be accorded to Dr. William Pole, F.R.SS. L. and E., Honorary Secretary, and to Mr. James Forrest, the Secretary, for their constant and assiduous attention to the affairs of the Institution.

Dr. Pole and Mr. Forrest returned thanks.

The Scrutineers then announced that the following gentlemen had been duly elected:

President.

SIR FREDERICK J. BRAMWELL, F.R.S.

Vice-Presidents.

Edward Woods.
George Barclay Bruce.
Sir John Coode.
George Berkley.

Other Members of Council.

Benjamin Baker.
John Wolfe Barry.
Sir Henry Bessemer, F.R.S.
Edward Alfred Cowper.
Sir James Nicholas Douglass.
Charles Douglas Fox.
Alfred Giles, M.P.
Harrison Hayter.
James Mansergh.
William Henry Preece, F.R.S.
Sir Robert Rawlinson, C.B.
Sir Edward James Reed, K.C.B., F.R.S., M.P.
Francis Croughton Stileman.
Sir W. Thomson, F.R.SS. L. & E.
Sir Jos. Whitworth, Bart., F.R.S.

Resolved,—That the thanks of the meeting be given to the Scrutineers, for the efficient manner in which they have discharged their task; and that the Ballot-Papers be destroyed.

[REPORT OF THE COUNCIL.

REPORT OF THE COUNCIL, SESSION 1884-85.

This is the first Annual General Meeting under the revised By-laws, which enact that the General Meeting shall be held on the last Tuesday in May (or, if that be a Whitsun Tuesday, then on the first Tuesday in June), instead of on the Tuesday next before Christmas Eve.

The revised By-laws requiring the accounts to be made up to the 31st of March, the Statement of Receipts and Expenditure now presented, contains the pecuniary transactions of only the four months between that date and the 30th of November, the period to which the accounts submitted to the Annual Meeting in December were carried. It has been thought proper that the return as to the changes in the several classes composing the Institution, or attached to it, should terminate at the same date. Under these circumstances no comparison is possible with any preceding year; but it may be mentioned that although the accounts relate to four months only, these months include that portion of the year in which the collection of the subscriptions is most active.

The Roll of the Institution.

On the 31st March, 1885, there were on the books 3944 members of all classes, of whom 20 were Honorary Members, 1485 Members, 1932 Associate Members, and 507 Associates. This return represents a net increase of 162 since the 30th of November, 1884. Seeing that the Candidates balloted for on three subsequent occasions would have to be added to these figures in order to compare with the year's total dealt with in the last report, while probably the majority of the resignations and the rateable proportion of other losses for the year are included, there is reason for congratulation at the progress thus recorded in the strength of the Institution.[1]

Admission of Students.

The Students attached to the Institution, but not forming part of the Corporation, constitute an increasing source of strength to the parent body; inasmuch as nearly one-half of those admitted are ultimately elected into the Corporation. In this way they join the Institution at the earliest possible age, and having, during their probation as Students, experienced the advantages of the connection, are the more likely to remain permanently attached to it. Although no formal test in the way of examination is at present provided, the Council takes pains to inform itself of the scholastic training each candidate has received, and is glad to be able to say that in most cases it is of a very high character. The Council is convinced the Students, as a body, are gentlemen who will be well worthy of election into the Corporation, and who may

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[1] The changes that have occurred during the four months ending March 31, 1885, are shown in the following Table (see next page):—

—	Nov. 30, 1883, to Nov. 30, 1884.					Nov. 30, 1884, to Mar. 31, 1885.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Numbers at commencement . .	20	1,355	1,701	512	3,588	20	1,416	1,844	502	3,782
Transferred to Members	..	..	44	1		..	..	37	2	
Do. to Associate Members . .	..	..	3	3		..	..	..	..	
Elections .	2	51	209	13	279	..	33	132	11	179
Restored to Register .	..	1	3	..		..	1	2	..	
Deaths . .	2	28	14	10	−85	..	3	5	3	−17
Resignations	..	6	7	6		..	1	4	1	
Erased . .	..	2	7	3	194	..	..	..	..	162
Numbers at termination	20	1,416	1,844	502	3,782	20	1,485	1,932	507	3,944

The Deceases have been :—

Members :—James Augustus Caley ; David Hughes Jones ; and Thomas Parker Watson, M.A.

Associate-Members :—Alexander Morton Bell ; Redmond John Brough ; Joseph William Jenkinson ; Francis William Otter ; and William Frederick Mayes.

Associates :—John Dunning ; John Prentis Hawley ; and William Charles Luard.

The Resignations were :—

Member :—William Bage.

Associate-Members :—Edward Colin Foote ; *Chevalier* Edward Rosenbusch ; Griffin William Vyse, B.A. ; and Charles Henry Billinghurst Whitworth.

Associate :—George Thomas Selby.

be relied upon to uphold the honour and character of the Institution. On the 30th of November, 1884, there were 722 Students. Up to the 31st of March 197 were admitted, while the retirements were 76 (including 47 elected into the Associate Member class), so that the number then on the books was 843.

AMENDED BY-LAWS.

For some two or three years past the Council has been made aware that an increasing number of country members desired that a change should be made in the day appointed for holding the Annual General Meeting. It was represented that the Tuesday before Christmas Eve was frequently an inconvenient day for them to be in town; and that it was especially so when Christmas-day occurred on the following Thursday. The Council took the matter into its serious consideration, and having carefully investigated the question, and weighed the relative advantages and disadvantages of a change, came to the conclusion embodied in the last report, viz., "The outgoing Council, while recognizing, as former Councils recognized, the difficulty of selecting a day that will be equally convenient to all the members, expresses the hope that its successors will take into consideration the propriety of altering the day, and will call a Special General Meeting of Corporate Members, at an early and convenient date, to make the necessary alteration in the By-laws." This recommendation having been unanimously approved by the Annual General Meeting, the present Council proceeded very shortly after its appointment to deal with the matter; and it having been clearly the wish of the General Meeting that a change should be made, its deliberations were in effect confined to the selection of the new date for the Annual Meeting which should be recommended for adoption. It had long been considered undesirable that there should be, in the middle of the session, a change in the Council and a change in the Presidency, and it was believed it would simplify matters very much if these changes were to take place at the end of the session. This would enable the incoming Council to make ready during the recess for the next session, and would give the new President time for the preparation of an address with which the session would be opened. These were reasons which made the Council deem it desirable to hold the Annual Meeting at the end of the session. But there were other reasons which appeared to point to the end of May as an acceptable time. In this month many members come to town for a number of purposes connected with Parliamentary Committees, and with business of various kinds; and very commonly the President's *conversazione* takes place at the end of May. Weighing all these circumstances the Council came to the conclusion that the last Tuesday in May, or, under the special circumstances which occur this year, the first Tuesday in June, was the best day to recommend for the Annual Meeting.

There were certain other matters in the By-laws which the Council believed might be altered for the common benefit, and it determined to take the opportunity of a Special Meeting being summoned, to submit to it propositions for making these alterations. Thus it came about that the circular convening the Special Meeting embraced three objects: the first, which has already been dealt with, the alteration of the date of the Annual Meeting; the second, the making more harmonious the needed qualifications of candidates; the third, the clearing up of obscurely worded passages.

With respect to the second object. There was a salutary provision in the By-laws, by which a candidate might be elected into the Institution as a full Member notwithstanding he might not have been regularly trained. The provision it will be remembered is as follows: "He shall have practised on his own account in the profession of a Civil Engineer for at least five years, and shall have acquired a considerable degree of eminence in the same." It was framed to meet the cases of persons who might have obtained such distinction in the profession that it would be an honour to the Institution to have them among its Members, although they could not point to a regular training. This paragraph enabled the Council to put forward for ballot the names of men of distinction as full Members. There was, however, no such paragraph with respect to the election of Associates entitled to the privileges of Corporate membership. There was a hard-and-fast rule that every candidate for election into the class of Associates entitled to the privilege of Corporate membership should "have been *regularly educated as a Civil Engineer*, and shall be actually engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter." Occasionally this was the cause of hardship. There came before the Council the names of candidates who were practising as engineers, and doing good engineering work, but who had not attained to such a position as would entitle them to come in as full Members. They were by their position perfectly eligible for Associate Members if they could say that they had been regularly educated and trained; but, if they were not able to make this statement, the Council with regret found itself compelled to reject them. That had happened not infrequently, and was likely to happen in the case of gentlemen in the Colonies. A man who had been trained by an architect, and had gone out to one of the Colonies, found himself there put into a variety of work. His architectural practice grew by degrees into engineering, and it might be that for years he had been doing very good work as an engineer, but still not such as to entitle him to be regarded as of sufficient distinction to become a full Member without the regular training. The Council felt it was a great hardship on a gentleman thus circumstanced that he could not be admitted as an Associate Member. To provide for this state of things the Council recommended for Associate Members the following alternative clause: "Or, he shall satisfy the Council that he has had a sufficient training, and that he has been engaged for at least five years, and that he is actually engaged at the time of his application for election, in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter." Another inconsistency was this: In the clause regarding the election of Associate Members it was a condition that they should not only have been regularly educated as Civil Engineers, but should "be actually engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer," whereas in the case of a Member there was no obligation that he should be actually so engaged. As the Member-clause stood it ran: "He shall have been regularly educated as a Civil Engineer according to the usual routine of pupilage, and have had subsequent employment for at least five years in responsible situations as Resident Engineer, &c.;" therefore a Member, as regarded his then occupation, was admitted upon easier terms than those which applied to an Associate Member. It appeared to the Council that the two classes ought to be put upon an equality, and that the words "and shall be actually engaged," should be inserted in reference to Members. With respect to the admission of Students, the By-laws as they stood imposed a verbal obligation which might not obtain with the Corporate Member who was privileged to propose a Student. A Student was not accepted unless he declared he was studying with the view of following the profession of a Civil Engineer. It appeared to the Council desirable that the words expressing the intention of the Student should be those words which have been so fully considered as being the best to apply to the condition of Associate Membership, namely, an intention of being "engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer, as defined by the Charter."

As some slight misapprehension exists as to the effect to be given to the condition, which now applies to Members as well as to Associate Members, that the candidate shall be "actually engaged at the time of his application for election, in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the charter," the Council desires to state that the words were only meant to be operative as against gentlemen who had left the profession, and were not intended to apply to engineers who were temporarily out of employment. Therefore the fear that has been expressed that the condition might press hardly on some gentlemen recently returned from abroad on the termination of an engagement, and who had not succeeded in obtaining another employment, was not well founded.

The third object, as already stated, was to make clearer certain passages in the By-laws. The alterations were principally verbal, but there were two matters of some importance. In Clause 1, Section VI., it was stated, "Those Members, Associates and Students, who reside within 10 miles of the General Post Office shall be considered Residents, and those beyond such limit Non-Residents." The By-laws were originally framed when there were no suburban railways, and when many of the members lived at their places of business, or at all events lived practically in London. Although the word "residence" was used it was almost universally understood by members that if they were employed in London, although the residence might be 12 or 20 miles out of town, yet London being the place of employment, they were Resident Members, and they paid the Residents' subscription. But in one or two cases the objection had been made that "residence" meant the place where a person slept, and that in cases where he did not sleep at his office, but in some suburb without the 10-mile radius, he was not a "resident," although his work was carried on in London, and although he had the full advantages of the Institution, and could come regularly to it and attend all the meetings. The Council thought it only fair that such persons, being in London, should be treated without any doubt or hesitation as Resident Members. The Council therefore proposed that the following words, which are in italics, should be substituted, "*whose place of business or whose residence is within* 10 *miles, &c., &c.*"

A question had also arisen as to the legality of "plumping" in the election of Council. It had been felt that the Institution was entitled to the judgment of all voters upon the whole Council; that the duty of the voter was not to exert himself to secure the election of a particular gentleman or of certain gentlemen in whom he felt an interest, but was to secure the return of twenty good names as constituting the whole Council of the Institution. This was the view expressed by counsel when some years ago an opinion was taken as to whether the By-laws as they stood forbade the practice of plumping. With the object of carrying out this view the Council recommended the omission from Section V., clause 3, the words "not exceeding," and the substitution of the words "be, without the repetition of any of them," the number to be elected to the respective offices.

After full discussion and consideration these recommendations were unanimously adopted by the Special General Meeting of Corporate Members on the 28th of April last. The details of the changes will be found in the report of that meeting (ante, p. 69).

Although by the terms of the revised By-laws the financial year ends on the 31st of March, the Council has considered that so far as regards the scientific work of the Society, its Report must embrace an account of the operations of the session now terminating. There have been twenty-four Ordinary Meetings, at which twelve Papers have been read and discussed, and one other Paper has been read, but its consideration has been postponed till next term. The subjects being still so fresh in memory will not further be alluded to, otherwise than to state that for some of these communications the Council has had much satisfaction in awarding medals and premiums as under:—A Watt Medal and a Telford Premium to Professor Henry Selby Hele Shaw, Assoc. M. Inst. C.E.; a George Stephenson Medal and a Telford Premium to William Stroudley, M. Inst. C.E.; a Telford Medal and a Telford Premium to Peter William Willans; and Telford Premiums to David Salmond Smart, Andrew Jamieson, F.R.S.E., Assoc. M. Inst. C.E., and William Shelford,[1] M. Inst. C.E.

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[1] Has previously received Telford and Watt Medals.

The special thanks of the Council have been accorded to its colleagues, Messrs. Benjamin Baker and John Wolfe Barry, for the valuable descriptions they gave of the design and construction of the important works of the Metropolitan and the Metropolitan District Railways. This action of the Council will, it is satisfied, be endorsed by the corporate members here present.

Although the subjects brought before the Institution this session have been few, it has been considered preferable to have a small number of communications thoroughly discussed rather than to have many subjects perfunctorily treated. To this end the same practice has been pursued during the past session as in several preceding ones of eliciting the views in writing of persons interested in the subjects but unable to attend the meetings, particularly of foreign engineers and men of science. The discussions, oral and written, thus recorded will it is confidently believed fully maintain the credit of the Institution; and it is suggested that the small number of Papers, far from being a matter of regret, should be a source of congratulation, as pointing to the conclusion that the subjects were matters of such real interest and importance as to amply justify the prolonged debates to which they gave rise.

The Council has also had the pleasure of awarding a medal and premiums to the Authors of Original Communications, which have been accepted for printing in the Minutes of Proceedings during the present year:—A Telford Medal and a Telford Premium, to William George Brounger, M. Inst. C.E.; and Telford Premiums to Professor William Cawthorne Unwin,[1] B.Sc., M. Inst. C.E.; Thomas Andrews,[2] F.R.S.E., Assoc. M. Inst. C.E.; John George Mair,[3] M. Inst. C.E.; James Craig, M. Inst. C.E.; and to Claude William Kinder, Assoc. M. Inst. C.E.

In regard to the Selected Papers, some of which afford ample evidence of the high scientific acquirements of their Authors, it may be well to reiterate that where a communication is printed in Section II. of the Minutes of Proceedings, it in no way implies that it is considered of inferior merit, but only that its subject is not so well suited for oral discussion as for private study. Medals of equal honour, and premiums of equal value, are awarded to the Authors of Papers in both sections, but the Selected Papers, being of later institution, take the second place in the Premium List.

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[1] Has previously received Telford and Watt Medals.

[2] Has previously received a Telford Medal.

[3] Has previously received a Watt Medal.

The origin of the Selected Papers may be briefly alluded to. For several years between 1860 and 1870, the Reports of the Council contained a paragraph couched much in this wise: "The publications of the Institution are at present limited to the printing of the Papers that are read, and the reports of the discussions which take place upon them; but the members of all classes have been invited to contribute short notes, not necessarily for reading at the meetings, giving the details and results of any experiments and observations on subjects connected with engineering science or practice, for the purpose of forming an Appendix to the Minutes of Proceedings." The suggestion originated with the late Mr. John Murray, M. Inst. C.E., when serving on the Council. He was of opinion that an engineer's note-book often comprised a store of information of the highest value and importance, but generally destined to oblivion by reason of the disinclination of its collector to spare the time and trouble necessary for the compilation of a set Paper. The idea has since been worked out far beyond its original scope, and has now developed into the well-known Section II., which, besides containing short notes and records of experiments, includes, and has included, memoirs which seem destined to become classic, as, for instance, the treatise of Mr. Wyatt, Associate Member, on the art of Paper-Making by the Machine, printed in the first volume of this Session.

SUPPLEMENTAL MEETINGS.

The Council is pleased to be able to report that it has been possible to hold twelve Students' meetings, at which as many Papers have been read, and that to eight out of those twelve Papers Miller prizes have been awarded. Further, five of the eight Papers so recognized have been deemed of sufficient merit to be printed in the Minutes of Proceedings. The Authors of successful communications are as under:—Frank Geere Howard, Stud. Inst. C.E.; Harley Hugh Dalrymple-Hay, Stud. Inst. C.E.; Wilfrid Scott Stokes, Stud. Inst. C.E.; Henry Tudsbury Turner, Stud. Inst. C.E.; William Kidd, Stud. Inst. C.E.; Sidney Richard Lowcock, Stud. Inst. C.E.;[1] Edward John Mines Davies, Wh. Sc., Stud. Inst. C.E.; and Frank Herbert Hebblethwaite, Stud. Inst. C.E.

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[1] Has since been elected an Assoc. M. Inst. C.E.

LECTURES.

The course of Lectures on Hydro-Mechanics announced in the last Report has since been delivered, as follows:—

"PHYSIOGRAPHY." By Mr. John Evans, V.P., & Treas. R.S., Assoc. Inst. C.E.
"WATER-SUPPLY." By Dr. William Pole, F.R.SS. L. and E., M. Inst. C.E., Hon. Sec.
"WATER-MOTORS." By Professor W. C. Unwin, B.Sc., M. Inst. C.E.
"INLAND NAVIGATIONS IN EUROPE." By Sir Charles Hartley, K.C.M.G., M. Inst. C.E.
"TIDES AND COAST-WORKS." By Mr. Thomas Stevenson,[1] Pres.R.S.E., M. Inst. C.E.
"FORM OF SHIPS." By Sir E. J. Reed, K.C.B., F.R.S., M. Inst. C.E., M.P.

The special thanks of the Institution are due to the eminent men who thus placed their services gratuitously at the disposal of the members.

CONTRIBUTIONS TO THE FUNDS AND FINANCE.

The statement of Receipts and Expenditure as signed by the Auditors, and which now lies on the table, shows that there has been received on account of income since the 30th of November last, comprising the most productive portion of the year, a sum of £11,061 8*s.* 7*d.*;—on account of capital (*i.e.* the entrance fees of new members and life-subscriptions) £1,973 15*s.*; and on account of Trust-investments £83 17*s.* 7*d.*; making the whole receipts for the four months and including a balance of £1,015 5*s.* 3*d.* brought into the account, £14,134 6*s.* 5*d.* On the other hand the Expenditure (which is more evenly distributed throughout the year) has been for the same period £4,297 5*s.* 11*d.* Investments have been made on capital account of £6,232 15*s.* The Trust-fund expenditure—*i.e.*, the premiums and prizes, has been £368 6*s.* 9*d.*, while there remained £3,235 18*s.* 9*d.* available (with the uncollected income yet to be received) for meeting the expenses of the remaining nine months of the present year.

The before-mentioned £6,232 15*s.*, stated as having been invested, has purchased £3,000 New Three per Cents. and £3,000 Metropolitan Board of Works Three-and-a-Half per cent. Stock. These further investments bring up the nominal capital of the Institution to £54,000, all of which is placed in such securities as are sanctioned by the Court of Chancery for trust-investments. No change has been made in the capital of the Trust-funds, which remains as at the 30th of November last, namely £14,642 13*s.* 10*d.*

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[1] In the unavoidable absence of Sir John Coode, V.P. Inst. C.E., who had undertaken to deliver the lecture on this subject.

In conclusion, the Council trusts the members will agree in thinking, that the experience of the period since the last Report, brief though it has been, is eminently satisfactory, and that there is good reason to hope the Institution will continue that career of honour and usefulness which it has pursued for so many years —a career which has caused it to rank among the foremost of those voluntary associations of private individuals for the promotion of public good, which, asking nothing from Government except the privilege of being left alone, have largely contributed to give to this country the prominent position she holds among the industrial nations of the world.

[RECEIPTS AND EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance, Nov. 30, 1884, viz. :—						
Cash in the hands of the Treasurer	1,014	12	11			
„ „ Secretary	0	12	4			
				1,015	5	3

Income.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
— Subscriptions :—									
Arrears	243	1	0						
Current	9,845	17	0						
Advance	19	2	6						
				10,108	0	6			
— Library-Fund				43	15	0			
— Minutes of Proceedings :—Repayment for Binding, &c.				116	13	4			
— Publication Fund				3	3	0			
— Miscellaneous Receipts				20	0	0			
— Dividends: 6 months on									

£.	*Institution Investments.*									
3,000	New Three per Cents.	0	0	0						
3,000	Caledonian Railway 4% Debenture Stock	0	0	0						
6,000	Great Eastern Ditto.	116	15	4						
3,000	Great Northern Ditto	58	7	6						
6,000	Great Western Ditto	116	15	0						
3,000	Highland Ditto	0	0	0						
6,000	Lancs. and Yorks. Ditto	116	15	0						
1,500	L. B. & S. C. Ditto	29	3	9						
6,000	L. & N. W. Ditto	116	15	0						
3,000	Midland Ditto	58	7	6						
3,000	North Eastern Ditto	58	7	6						
1,500	L. B. & S. C. 4½% Ditto	32	16	9						
3,000	Man. Shef. & L. Ditto	65	13	5						
	New Purchases.									
3,000	New Three per Cents	0	0	0						
3,000	Met.Bd.of Wks. 3½% Stock	0	0	0						
£54,000	Total nominal or par value.				769	16	9			
								11,061	8	7

	£.	s.	d.
Carried forward	£12,076	13	10

from the 1st DEC., 1884, *to the* 31st MARCH, 1885.

EXPENDITURE.

Cr.

General Expenditure.

	£.	s.	d.	£.	s.	d.
By House and Establishment Charges:—						
Asphalt Pavement	84	10	0			
Repairs, General	60	12	3			
Rent	315	6	6			
Rates and Taxes	130	15	0			
Insurance	41	16	6			
Fixtures and Furniture	86	5	6			
Lighting and Warming	57	17	1			
Refreshment at Meetings	38	1	9			
Assistance at Meetings	16	10	0			
Students' Meetings	12	13	10			
Household Expenses	54	1	0			
				898	9	5
— Postages, Telegrams, and Parcels	84	15	11			
— Stationery and Printing	279	18	2			
— Watt Medal	2	7	6			
— Diplomas	33	11	8			
— Annual Dinner (Postage)	0	10	1			
				401	3	4
— Salaries	950	0	0			
— Clerks, Messengers, and Housekeeper	234	3	4			
— Donation to late Housekeeper	15	0	0			
				1,199	3	4
— Library:—						
Books	131	7	2			
Periodicals	40	13	9			
Binding	22	3	0			
				194	3	11
— Publication:—						
"Minutes of Proceedings" Vol. lxxix., (in part) and Name-Index to Vols. i.-lviii.	1,570	2	4			
Lectures on "Hydro-Mechanics"	28	3	7			
— Bust of Smeaton (Replica presented to the Smeaton Memorial Committee)	6	0	0			
				1,604	5	11
Carried forward				£4,297	5	11

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

	Dr.			£. s. d.
	Brought forward			12,076 13 10
	CAPITAL.		£. s. d.	
	To Admission-Fees		1,737 15 0	
	— Life-Compositions		236 0 0	1,973 15 0
	TRUST-FUNDS.			
	To Dividends: 6 months on			
£. s. d.	*Telford Fund.*	£. s. d.		
5,425 11 9	Three % Consols	79 0 3		
3,290 13 0	Three % Reduced (Unexpended Dividends)	0 0 0		
8,716 4 9	Total nominal or par value.		79 0 3	
	Manby Donation.			
250 0 0	Great Eastern Ry. Four % Debenture Stock.		4 17 4	
	Miller Fund.			
3,125 0 0	New Three per Cents.	0 0 0		
1,999 14 7	Three % Reduced (Unexpended Dividends)	0 0 0		
5,124 14 7	Total nominal or par value.		0 0 0	
	Howard Bequest.			
551 14 6	New Three per Cents.		0 0 0	83 17 7
				£14,134 6 5

SUMMARY OF INVESTMENTS.

	£. s. d.	£. s. d.
INSTITUTION-INVESTMENTS		54,000 0 0
TRUST-FUNDS—		
Telford Fund	8,716 4 9	
Manby Donation	250 0 0	
Miller Fund	5,124 14 7	
Howard Bequest	551 14 6	14,642 13 10
		£68,642 13 10

from the 1st DEC., 1884, *to the* 31st MARCH, 1885.

EXPENDITURE—*continued.*

Cr.

£.		£. s. d.	£. s. d.	£. s. d.
	Brought forward			4,297 5 11
	CAPITAL-INVESTMENTS.			
By 3,000	New Three per Cents.		2,996 5 0	
— 3,000	Metropolitan Bd. of Works 3½ % Stock		3,236 10 0	
£6,000	Total nominal or par value.			6,232 15 0
	TRUST-FUNDS.			
	By Telford Premiums	214 6 3		
	— Telford Medals	12 0 0	226 6 3	
	— Miller Scholarships	80 0 0		
	— Miller Prizes	62 0 6	142 0 6	368 6 9
				10,898 7 8
	— Balance, March 31st, 1885, viz.:—			
	On Deposit at Bankers		2,000 0 0	
	Cash in the hands of the Treasurer		935 6 5	
	" " Secretary		300 12 4	3,235 18 9
				£14,134 6 5

Examined with the Books and found correct.

(Signed) EDWARD BAZALGETTE } *Auditors.*
H. BAUERMAN

JAMES FORREST, *Secretary,*
15*th May,* 1885.

PREMIUMS AWARDED.

SESSION 1884–85.

THE COUNCIL of The Institution of Civil Engineers have awarded the following Premiums:

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Watt Medal and a Telford Premium to Professor Henry Selby Hele Shaw, Assoc. M. Inst. C.E., for his Paper on "Mechanical Integrators."
2. A George Stephenson Medal and a Telford Premium to William Stroudley, M. Inst. C.E., for his Paper on "The Construction of Locomotive Engines."
3. A Telford Medal and a Telford Premium to Peter William Willans, for his Paper on "Electrical Governors."
4. A Telford Premium to David Salmond Smart, for his Paper on "The Modern Practice in the Construction of Steam-Boilers."
5. A Telford Premium to Andrew Jamieson, F.R.S.E., Assoc. M. Inst. C.E., for his Paper, "Electric Lighting for Steamships."
6. A Telford Premium to William Shelford,[1] M. Inst. C.E., for his Paper, "On Rivers Flowing into Tideless Seas, illustrated by the River Tiber."

⁂ The special Thanks of the Council were voted to its colleagues, Messrs. Benjamin Baker and John Wolfe Barry, for their Papers on "The Metropolitan and the Metropolitan District Railways."

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING DISCUSSED.

1. A Telford Medal and a Telford Premium, to William George Brounger, M. Inst. C.E., for his Paper on "The Cape Government Railways."
2. A Telford Premium to Professor William Cawthorne Unwin,[1] B.Sc., M. Inst. C.E., for his Paper, "Experiments on the Friction of Disks rotated in Fluid."

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[1] Have previously received Telford and Watt Medals.

3. A Telford Premium to Thomas Andrews,[1] F.R.S.E., Assoc. M. Inst. C.E., for his Paper on "Corrosion of Metals during long Exposure in Sea-water."
4. A Telford Premium to John George Mair,[2] M. Inst. C.E., for his Paper on "The Results of some Independent Engine-Tests."
5. A Telford Premium to James Craig, M. Inst. C.E., for his Papers on "Discharge from Catchment-Areas."
6. A Telford Premium to Claude William Kinder, Assoc. M. Inst. C.E., for his Paper, "Notes on Electric Blasting in China."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. A Miller Prize to Frank Geere Howard, Stud. Inst. C.E., for his Paper on "Secondary Batteries."
2. A Miller Prize to Harley Hugh Dalrymple-Hay, Stud. Inst. C.E., for his Paper on "Trigonometrical Surveying."
3. A Miller Prize to Frederick Wilfrid Scott Stokes, Stud. Inst. C.E., for his Paper on "The Iron Bridges of the Hull and Barnsley Railway."
4. A Miller Prize to Henry Tudsbury Turner, Stud. Inst. C.E., for his Paper on "The Gauging of Flowing Water."
5. A Miller Prize to William Kidd, Stud. Inst. C.E., for his Paper on "The Blasting and Removal of Rock under Water, and the Construction of a Deep-water Quay at Blyth Harbour."
6. A Miller Prize to Sidney Richard Lowcock, Stud. Inst. C.E.,[3] for his Paper on "The Water-Supply, Sewerage, and Sewage-disposal Works at Wellington College."
7. A Miller Prize to Edward John Mines Davies, Wh. Sc., Stud. Inst. C.E., for his Paper on "Heat-Engines."
8. A Miller Prize to Frank Herbert Hebblethwaite, Stud. Inst. C.E., for his Paper on "The Difference in Design of British and Foreign Locomotive Engines."

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[1] Has previously received a Telford Medal.
[2] Has previously received a Watt Medal.
[3] Has since been elected an Assoc. M. Inst. C.E.

SUBJECTS FOR PAPERS.

Session 1885–86.

The Council of The Institution of Civil Engineers invite Original Communications on any of the Subjects included in the following list, as well as on other questions of professional interest. For approved Papers the Council have power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £250 annually.

2. The Manby Donation, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises £160 per annum. Out of this Fund the Council have established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and are prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to rather more than £16. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1887.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made (except in the cases of the Miller and the Howard bequests, which are limited by the donors) between essays from any person, whether belonging to the Institution or not, or whether a Native or a Foreigner.

LIST.

1. Recent Experiments on the Strength of Materials.
2. Machines and Apparatus for testing Metals, and the Equipment generally of Mechanical Laboratories.
3. The Thermic Properties of Metals commonly used in the Arts, especially with respect to Conductivity and Diathermancy at high temperatures.
4. The manufacture, properties, and use of Castings of Malleable Cast-Iron and Cast-Steel.
5. The Effect of Cold-Hammering and Cold-Rolling upon Iron and Steel.
6. The Present Position of the Manufacture of Steel—its defects, and suggestions for its improvement.
7. The various Processes of Tempering Steel, and their effects.
8. Modern Machine-tools and Workshop Appliances for the treatment of Heavy Forgings and Castings.
9. The Testing of Work done by Motors and Machines.
10. Analyses of different types of Steam-Engines as shown by Independent Testing.
11. The Production of Heating-Gas from Coal.
12. The Production of Ammonia and other useful substances in the Manufacture of Coal-Gas.
13. The heating of Steam-boilers with Producer-Gas.
14. The Manufacture of Artificial Fuel from small Coal.
15. The Application of the Compound Principle to Locomotive and Portable Engines.
16. The Driving-axles of Locomotive Engines.
17. High-speed Engines for Dynamos and Launches.
18. The Machinery of Modern War Ships.
19. Machine-Guns.

20. On Built-up Crank-Shafts for Marine Engines, and on the liability of crank- and screw-shafts to fracture.
21. The Structural and other Defects to which Iron and Steel Ships are subject, and their Causes.
22. Recent Investigations on the Tides.
23. Descriptions of recent Graving-docks, Gridirons and Floats.
24. Promenade- and other Piers; with reference to the effect of Sea-water on wrought- and cast-iron structures, and the best means of preserving the same.
25. Dredging-Machinery for small Harbours, and for Drainage- and Irrigation-Canals.
26. The Economical Construction and Operation of Railways in countries where small returns are expected.
27. Descriptions of recent Metallic Arch Bridges.
28. The Machinery and Labour-saving Appliances used in the Execution of Public Works and Buildings.
29. The Ventilation of Sewers, with a summary of Experiments as to the motion, pressure, &c., of gas in sewers.
30. Filter-Presses for separating Solids from Fluids, particularly for the treatment of Sewage-Sludge.
31. Explosions in Coal-Mines; their Causes, Warnings, and Prevention.
32. Winding-Machinery and Balancing-Apparatus for Mines, and the cost per ton of winding under different conditions and varying depths.
33. Under-ground Haulage, especially on the application of compressed air and of electrical power.
34. The Methods employed in securing large and irregular-shaped mineral workings.
35. The Manufacture of Common Salt, including the mining of Rock Salt and Brine-pumping.
36. Gold Quartz-crushing and amalgamating-appliances.
37. The Manufacture and Desilverization of Lead.
38. Appliances for the rapid Shipment of Coals, with a comparison of different methods.
39. Electro-Motors; their theory, practical construction, efficiency, and power.

40. The Construction of Dynamo-Electric Machines and their Prime-Movers.
41. The Working and Cost of the Treble- and Double-Wire Systems of distributing Currents for Electric Lighting.
42. Thermo-Electric Batteries, and their Application to Electric lighting, Electro-plating and other purposes.

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract not exceeding 1500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, and ready to be engraved. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly coloured to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, cannot be read at a Meeting of the Institution, nor be admitted in competition for the Premiums.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it is dealt with in the succeeding one.

WILLIAM POLE, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

THE INSTITUTION OF CIVIL ENGINEERS,
25, *Great George Street, Westminster, S.W.*
August, 1885.

EXCERPT BY-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution as a body must not be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1, 1884, AND MARCH 31, 1885.

AUTHORS.

Aspinall, J. A. F. No. 2,068.—Crank Axles. With a Drawing and 18 Photographs.

Baker, B. No. 2,054.—The Metropolitan and Metropolitan District Railways. With Illustrations. (Vol. lxxxi., p. 1.)

Barry, J. W. No. 2,060.—The City Lines and Extensions (Inner Circle Completion) of the Metropolitan and District Railways. With Illustrations. (Vol. lxxxi., p. 34.)

Briffault, F. No. 2,055.—Constantinople Waterworks. With 2 Sheets of Drawings.

Brightmore, A. W. No. 2,071.—Experiments on the Steam-Engine Indicator. (Appendix to No. 2,070, On the Theory of the Indicator and the Errors in Indicator-Diagrams.)

Brounger, W. G. No. 2,049.—The Cape Government Railways. With Maps and Diagrams. (Vol. lxxxi., p. 252.)

Brunton, D. W. No. 2,064.—The Copper Mines of Butte City, Montana, with an Estimate of the Amount and Cost of Production. With 5 Photographs. (*Post*, p. 271.)

Craig, J. No. 2,047.—Maximum Flood-Discharge from Catchment-Areas, with special reference to India. With 4 Drawings. (Vol. lxxx., p. 201.)

———. No. 2,058.—Mean Coefficient of Discharge from Catchment-Areas. (Vol. lxxx., p. 213.)

Deprez, M., and Leblanc, M. No. 2,066.—Comparative Study of Various Methods of Traction applicable to Railways. (Vol. lxxxi., p. 265.)

Grantham, R. F. No. 2,061.—The Separate System of Sewerage. With 3 Drawings.

Guillain, H. No. 2,065.—Cost of Dredging at Calais and at Boulogne. (Vol. lxxx., p. 260.)

Hallé, G. No. 2,071.—The Public Works of the Orange Free State, South Africa. With 5 Photographs. (Vol. lxxxi., p. 272.)

James, C. No. 2,056.—Method of Removing Rock under Water, as adopted in the Enlargement and Deepening of the Harbour and Entrance-Channel to the Welland Canal at Port Colborne. (Vol. lxxx., p. 232.)

Longridge, J. A. No. 2,073.—Guns Considered as Thermo-dynamic Machines. (Vol. lxxx., p. 236.)

Reynolds, O. No. 2,070.—On the Theory of the Indicator and the Errors in Indicator Diagrams. (Abstract *ante*, p. 232.)

Shaw, H. S. Hele. No. 2,063.—Mechanical Integrators. With 55 Illustrations. (*Ante*, p. 75.)

Shelford, W. No. 2,069.—On Rivers flowing into Tideless Seas, illustrated by the River Tiber. With illustrations. (*Ante*, p. 2.)

Strachan, J. No. 2,050.—Karachi Waterworks. With 9 Sheets of Illustrations.

Tripp, W. B. No. 2,046.—The River Buffalo; total Flow at the Town Dam, King William's Town, Cape of Good Hope, from June 1880 to March 1883, compared with the Rainfall. With an Appendix and Tables. (Vol. lxxxi., p. 241.)

Unwin, W. C. No. 2,051.—Experiments on the Friction of Disks Rotated in Fluid. With Appendix, and 5 Sheets of Illustrations. (Vol. lxxx., p. 221.)

Ward, H. No. 2,057.—Brickmaking. With 24 Sheets of Illustrations.

Webb, F. W. No. 2,074.—Standard Engine-Shed, of the London and North-Western Railway Company. With 1 drawing. (Vol. lxxx., p. 258.)

Willans, P. W. No. 2,059.—The Electrical Regulation of the Speed of Steam-Engines and other Motors for Driving Dynamos. (Vol. lxxxi., p. 166.)

LIST OF DONORS TO THE LIBRARY.

From December 1, 1884, to March 31, 1885.

A.

Abel, Sir F.
Académie Royale de Belgique.
Admiralty.
Agent-General for New South Wales.
Agent-General for Victoria.
Agudio, T.
Akademie des Bauwesens.
Akademie der Wissenschaften.
Alrole, P. de.
American Academy of Arts and Sciences.
American Association for the Advancement of Science.
"American Engineer."
American Institute of Mining Engineers.
"American Manufacturer."
American Society of Civil Engineers.
American Society of Mechanical Engineers.
"Anales de Obras Pùblicas."
"Annales des Mines."
"Annales Industrielles."
Architekten- und Ingenieur-Verein für Böhmen.
Architekten- und Ingenieur-Verein für Hannover.
Architekten- und Ingenieur-Verein für Niederrhein und Westfalen.
Art Union of London.
Asiatic Society of Bengal.
Association Amicale des Anciens Élèves de l'École Centrale.
Association des Ingénieurs sortis de l'École de Gand.
—— —— sortis de l'École de Liége.
—— of Engineering Societies, U.S.
—— of Municipal and Sanitary Engineers.
"Athenæum, The."

B.

Bagot, Alan.
Bailey-Denton, J.
Balmokand, L.
Barclay, A.
Barnett, J. Davis.
Barrett, L.
Bateman, J. F. La Trobe.
Bauschinger, Prof.
Ben'et, Brigadier-Gen. S. V., U.S.A.
Bennett, W. H.
Blackett, J.
Blanford, H. F.
Bolton, Col. Sir F.
Bouhy, V.
Bowie, Aug. J. J.
Brereton, R. M.
British Association for the Advancement of Science.
British Iron Trade Association.
Brown, S.
Browne, H. J.
"Builder, The."

C.

Calcraft, H. S.
Cambridge Philosophical Society.
" Canadian Magazine, The."
" Canal de Suez, Bulletin."
" Canal Interocéanique, Bulletin."
Carpmael, A. and E.
" Centralblatt der Bauverwaltung."
Chemical Society.
Chesterfield and Derbyshire Institute of Engineers.
Chief of Engineers, U.S.A.
Churruca, E. de.
Clark, E. H.
Clark, J. Latimer.
Cleveland Institute of Engineers.
Coghlan, J.
Collegio degli Architetti ed Ingegneri in Firenze.
Collegio degli Architetti ed Ingegneri in Genova.
Collegio degli Architetti ed Ingegneri in Milano.
Collegio degli Architetti ed Ingegneri in Roma.
Colonial Secretary, Cape of Good Hope.
Comité des Forges de France.
Commissioners of Patents, H. M.
" Contract Journal, The."
Corthell, E. L.
Couche, M.
Creswell, C. E.
Crook, H. T.
Cruls, L.

D.

Darley, C. W.
Dawkins, W. Boyd.
Deas, J.
Deering, W. H.
Department of Mines and Water-Supply of Victoria.
—— of State, U.S.A.
—— of the Interior, U.S.A.
—— of the Navy, U.S.A.
—— of War, U.S.A.
" Deutsche Bauzeitung."
Dyer, H.
Dyckerhoff and Sons.

E.

Eads, J. B.
École des Mines, Paris.
École des Ponts et Chaussées, Paris.
École Polytechnique de Delft.
" Electrical Engineer, The."
" Electrical Review, The."
" Electrician, The."
" Electricien, l'."
" Engineer, The."
" Engineering."
" Engineering News."
Engineers' Club of Philadelphia.
Engineers' Club of the Northwest.
Engine, Boiler, and Employers' Liability Insurance Co.
Éscola de Minas de Ouro Preto.

F.

Fanning, J. T.
Fink, A.
Fitzgerald, D.
Francis, J. B.
Frankel, W.

Franklin Institute.
Fraser, J.

G.

Gamble, J. G.
"Gas-Light Journal."
Geddes, P.
Gendebien, A.
"Génie Civil, Le."
Geological Society.
"Giornale dei Lavori Pubblici."
"Giornale del Genio Civile."
Gisborne, F. N.
"Glaser's Annalen für Gewerbe und Bauwesen."
Gore, R. B.
Government of Bengal.
Gray, S. M.
Guerriere, J. V.

H.

Harbour- and Land-Commissioners, U.S.
Harrison, J. F.
Hayter, Hon. H. H.
Haywood, Col. W.
Hector, Dr. J.
Herschel, Clemens.
Hewson, T.
Hill, Luke M.
Hirn, G. A.
Hirsch, J.
Homersham, Collett.
Hüet, A.

I.

Imperial Russian Admiralty.
India Office.
"Ingegneria Civile."
Ingeniörs Förening.
Institute of Patent-Agents.
Institution of Civil Engineers of Ireland.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
"Iron."
"Iron and Coal Trades Review."
Iron and Steel Institute.

J.

Journal des Travaux Publics.

K.

Kellar, Karl.
Kew Observatory.
Königliche Bayerische Akademie der Wissenschaften.
Koninklijk Instituut van Ingenieurs.
Königliche Technische Hochschule zu Berlin.

L.

Langtree, C. W.
Leavitt, E. D.
Leloutre, G.
Lesseps, Sir F. de.
"Library Journal, The."
Lightfoot, T. B.
Lighthouse Board, U.S.A.
Lindley, W. H.
Literary and Philosophical Society of Liverpool.
Liverpool Free Public Library.
Liverpool Polytechnic Society.
Lloyd's Register.
Local Government Board.
Longridge, J. A.

M.

Mackinlay, Major M.
Magyar Mernök.

Manchester Literary and Philosophical Society.
Manchester Public Library.
Manchester Steam Users' Association.
Mansergh, J.
Mason Science-College, Birmingham.
Massachusetts State Board of Health.
Master Car-Builders' Association.
Meade, T. de Courcy.
Merchant and Co.
Mestayer, R. L.
Metcalf, W.
Meteorological Office.
Michael, M. J.
Michäelis, W.
Miller, H., Junr.
Mining Institute of Cornwall.
Minister of Marine and the Colonies of France, H.E. the.
—— of Public Works of Belgium.
—— —— Canada.
—— —— France.
—— —— Italy.
—— of Railways and Canals of Canada.
Moore, W. J. P.
"Mouvement Industriel Belge, le."
Murgue, D.

N.

National Boiler-Insurance Association.
National Smoke-Abatement Institution.
Newlands, J. A. R.
Newton, A. V.
New York State Survey.
New Zealand Institute.
Nicoll, Donald.
Nisbet, W. D.
Nordling, W. von.
Norske Ingeniör og Architekt Förenings.
North of England Institute of Engineers.
Nourse, J. E.

O.

Observatory of Rio de Janeiro.
O'Brien, G.
Oesterreichischer Ingenieur-und Architekten-Verein.
Olive, W. T.

P.

Paur, H.
Peabody Institute.
Pennsylvania Railroad Co.
Perry, Rev. S. J.
Philosophical Society of Glasgow.
Physical Society.
Pi Eta Scientific Society.
Pole, Dr. W. (*Hon. Sec.*)
"Politecnico, Il."
Prindle, F. C.
Public Works Department, N.W.P., India.

R.

Railroad Commissioners, U.S.A.
"Railway Engineer."
Reale Accademia dei Lincei.
Reale Istituto Lombardo.
Registrar-General of Victoria.
Rensselaer Society of Engineers.
"Revista de Engenharia."
"Revista de Obras Publicas (Lisbon)."

"Revista de Obras Pùblicas (Madrid)."
"Revue Générale de l'Architecture."
"Revue Générale des Chemins de fer."
"Revue Universelle des Mines."
Robinson, H.
Rock, J.
Roth, H. L.
Rowley, W.
Royal Agricultural Society.
—— Artillery Institution.
—— Astronomical Society.
—— Colonial Institute.
—— Cornwall Polytechnic Society.
—— Dublin Society.
—— Engineers' Institute.
—— Geographical Society.
—— Indian Engineering College, Cooper's Hill.
—— Institute of British Architects.
—— Institution of Great Britain.
—— Irish Academy.
—— Meteorological Society.
—— Society of Edinburgh.
—— —— of London.
—— —— of New South Wales.
—— —— of Queensland.
—— —— of South Australia.
—— —— of Victoria.
—— United Service Institution.
Ržiha, F. von.

S.

Sächsischer Ingenieur- und Architekten Verein.
Sala, P. P.
"Sanitary Engineer."
Sanitary Institute of Great Britain.
School of Practical Science, Toronto.
Schreiber, C.
"Science."
Scott, R. H.
Seismological Society of Japan.
Sellers, Coleman.
Selwyn, A. R. C.
Shaw, Capt. E. M.
Shone, Isaac.
Silverthorne, A.
Smith, Willoughby.
Smithsonian Institution.
Sociedad Cientifica Argentina.
Société des Ingénieurs-civils, de Paris.
—— Industrielle de Mulhouse.
—— —— de Rouen.
—— —— de St. Quentin.
—— Scientifique et Industrielle de Marseille.
—— vaudoise des Ingénieurs et des Architectes.
—— for Psychical Research.
—— of Arts.
—— of Chemical Industry.
—— of Engineers.
—— of Telegraph Engineers and Electricians.
Spon, E.
Stanton, Col. F. S.
Statistical Society of London.
State Board of Health. Lunacy and Charity, U.S.
"Steamship."
Stewart, J. A.
Sugg, W. T.
Surgeon-General, U.S.A.
Surveyors' Institution.
Swan, C. H.
Symons, G. J.

T.

Tarbotton, M. O.
Tekniske Förening.
Thomason Civil Engineering College.
Thurston, R. H.
Thwaite, B. H.
Tokio University.
Trendell, A.
Tweddell, R. H.

U.

United States Lighthouse Board
—— —— Naval Institute.
University College, Bristol.
Urquhart, T.

V.

Van Nostrand, D.
Vernon-Harcourt, L. F.

W.

Waddell, J. A. L.
Waring, G. E., Junr.
Weedon, J. F.
——, F. M.
Weyrauch, J. J.
Widmer, E.
Williams, A.
Woodbury, C. J. H.
Woods, J. James.

The Donations to the Library Fund were as under:—

	£.	*s.*	*d.*
Bayley, G. H.	2	2	0
Birch, E. R.	3	3	0
Bourne, J. J.	1	1	0
Brigden, Jas.	2	0	0
Creswell, R. E.	2	2	0
Dartnall, W. W.	1	1	0
Hack, R.	7	7	0
Hanson, E. B.	1	1	0
Honeysett, A.	1	1	0
Langdon, W.	3	3	0
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MacLean, F. W.	1	1	0
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Thompson, A. G.	2	12	6
Wallace, L. A.	5	5	0
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Young, J. B.	1	1	0
———, J. D.	2	7	6
	£43	15	0

5 June, 1885.

The Session was concluded by a Conversazione, which was given by the President and Lady Bramwell, from nine to twelve P.M., at the International Inventions Exhibition, South Kensington, by permission of the Executive Council. The members of the Institution and a distinguished circle of visitors, numbering 7,120 persons, were received in the vestibule. During the evening the Strauss orchestra played in the Eastern Kiosk, the band of the Coldstream Guards in the Western Kiosk, and the band of the Royal Irish Constabulary in the South Gallery; there were also organ-recitals in the Central Gallery, and other musical recitals in the Music-Room.

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⁂ *This Council will continue till May* 1886.

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SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2064.*)

"The Copper Mines of Butte City, Montana, with an Estimate of the Amount and Cost of Production."

By DAVID WILLIAM BRUNTON, M. Inst. C.E.

BUTTE CITY, near which the mines are situated, is a town of some eight thousand inhabitants in Silver Bow county, on the line of the Utah and Northern Railway, 417 miles north of Ogden, Utah, where connections are made with the Union Pacific, Central Pacific, Denver and Rio Grande Western and Utah Central Railways. The northern terminus of the Utah and Northern Railway is at Garrison, 621 miles north of Butte, and on the Northern Pacific Railroad.

From Butte City to the principal points to which freight rates are made, in accordance with the pooling contracts governing all connecting and competing railways, the distances are: to Omaha, Nebraska, *viâ* Utah and Northern and Union Pacific Railways, 1,452 miles; to San Francisco, California, *viâ* the Utah and Northern and Central Pacific Railways, 1,312 miles; to Duluth, Minnesota, on Lake Superior, *viâ* the Utah and Northern and Northern Pacific Railways, 1,234 miles; to Portland, Oregon, *viâ* Utah and Northern and Northern Pacific Railways, 759 miles, and *viâ* Utah and Northern and Oregon Short Line, 993 miles.

The City is situated at an altitude of 5,492 feet on the northern side of Silver Bow Gulch, a once famous placer ground. The climate, though very cold during the winter months, is exceedingly healthy and not unpleasant. The prevalence of diphtheria among children, and the dense clouds of sulphurous acid fumes from the smelting works, are about the only objectionable features to life in Butte City; what, if any, connection exists between these two noticeable facts is not yet determined.

The mines are found in a low range of granite hills north of the city, and east of the Butte (a conical-shaped mountain) from which the place derives its name.

While all the mines carry more or less silver and, generally, traces of gold, those at the eastern end of the belt are worked and known almost exclusively for their copper. In fact, the mines of Butte are naturally divided into two great classes—one, on the western half of the belt, carrying silver in paying quantities, and distinguished on the surface by an outcrop of hard quartz, stained black by oxide of manganese from the alteration of manganese carbonate and silicate which are found as depth is gained; and the other class on the eastern portion of the mineral belt, carrying copper, and marked on the surface by an outcrop of iron-stained quartz.

Few of the copper mines carried rich copper ores near the surface, and several of them were worked to a considerable depth for free-milling silver ores before reaching the heavy copper ores that have made the locality famous.

Only three of the great ledges in the district have as yet been explored. On the northern one are located the silver-mines of the Alice and the Moulton Companies, producing about $175,000 (£36,000) per month in gold and silver bullion; on the central ledge are the Lexington Company's silver mines, with a bullion yield of $90,000 (£18,500) per month; and on the southern are found the Parrot, Anaconda, Mountain View, Liquidator, and Colusa, nearly all the great copper mines of the district. The properties mentioned are not by any means all of the "locations" made on either the silver or the copper ledges, but they include the well-developed and producing mines on the central portion of each lode. Besides these well-explored large veins, there are many smaller ones now being "prospected," and in the western part of the district several very prominent ledges, until now unexplored, are beginning to attract attention. These latter, from their situation and the indication afforded by their outcrops, may be expected to produce copper, rather than silver ores. Even where no prominent outcrops are visible, new copper veins are likely to be found; for the soft rock in which such veins always occur in this locality, degrades more rapidly than the enclosing granite. Already, in many instances, cross-cuts from the lower levels of developed mines have intersected large ore-bodies in veins of which not the slightest trace can be discovered on the surface.

The country rock is everywhere a true granite, and no especial difference that will hold good over any considerable area can be discovered between the rock in the eastern, and that in the western portion of the district.

Both the silver and copper ledges occur in well-defined belts of quartz-porphyry or altered granite, and the width of these belts, generally increasing toward the east and diminishing toward the west, is almost the only appreciable difference between the silver and copper lodes. On the great copper ledge, this quartz-porphyry body varies greatly, not only in width (from 10 to 1,000 feet), but also in hardness and composition, the proportion of quartz to feldspar being far from constant.

There are two veins in most of the mines, one near the hanging- and the other near the foot-wall of the porphyry belt; but even this position is not always maintained, as the vein near the foot-wall generally pitches toward the south more rapidly than does the one near the hanging-wall. In some of the mines the porphyry belt is split up into two portions, separated from each other by from 10 to 40 feet of granite. Diagonal veins or feeders run into the main vein from the north in many places, and seem to increase the volume of ore for some distance beyond the point of junction.

The main copper ledge runs at right angles to the ravine system, and it is curious that in spite of great differences in the altitude of the croppings, that the rich ores begin to appear in all the mines at nearly the same datum level. Mines situated in the gulches (ravines), such as the Parrot to the west, and the Colusa in the east, encountered good copper ore within 100 feet of the surface, while the mines located on the sides and on the summits of the intervening ridges sank through nearly barren rock for greater distances, in one instance 500 feet, before pay-ore was reached. The numerous ore- and waste-dumps on the surface afford a ready clue to the impoverished condition of the higher portions of the vein. No matter how hard and dense the ore and its enclosing gangue may be when hoisted to the surface, a few months' exposure to the air disintegrates the larger portion of it into fine sand, while by oxidation and partial solution of the copper sulphides, the colour of the mass changes from a light grey to a greenish blue. Above the water-line, especially in the ridges, the vein matter has been subjected to a slow oxidizing and leaching process—a fact which undoubtedly accounts for its present lean condition, and explains why rich bodies of copper ore are rarely encountered above "water-level."

Although small specimens of very many species of minerals may be discovered by careful search, the number of these found in quantity in the Butte mines is comparatively small. Iron pyrites (pyrite), copper-glance (chalcocite) and peacock ore (erubescite), form the bulk of the ores, copper pyrites (chalcopyrite) being scarce, and grey copper ore (tetrahedrite) almost entirely wanting. As, however, erubescite may be considered to be produced by the alteration of copper pyrites, it is reasonable to suppose that the latter will become more abundant with increase in depth, and that the value of the ore will be depreciated by the absence of the richer mineral.

On the explored belt, which is now over 7,000 feet in length, the ore shoots vary in width from a few inches to 50 feet, and in quality from iron pyrites, carrying a small percentage of copper, to nearly pure copper glance; but the present developments are insufficient to admit of the forming of any idea as to the ratio of pay to barren ground.

In Butte mining parlance, first-class ore means nearly pure copper, glance running from 30 to 50 per cent. in copper; second-class, copper-glance or peacock ore mixed with iron pyrites, and assaying from 20 to 30 per cent. in copper; and third-class, or concentrating ores, those varying in assay from 8 to 20 per cent. of copper. Until the present time, lack of concentrating-machinery, and an excessively high freight-rate, have compelled the miners to "gouge out," as much first-class ore as possible.

None of the mines are developed to any great depth, and in few of them have the second- and third-class ores been stoped out from any considerable portion of the ground already explored.

It is impossible to estimate with any degree of accuracy the relative proportions of first-, second-, and third-class ores in the belt, because they have never been mined in the ratio in which they exist in the veins, but a careful examination can hardly fail to convince any one that the great mass and value of Butte's copper wealth are in the immense bodies of third-class, which everywhere forms the largest portion of the ores. Nor is this any great drawback to the production of the district, nor to the value of the mines, for with cheap concentration and abundant smelting-facilities, copper can be produced almost if not quite as cheaply by stoping out 15 or 20 feet of 10 to 15 per cent. ore, as by mining a narrow streak of 30 to 40 per cent. ore.

The first shipment of copper ore was made in 1867, but nothing of any importance was done until 1879, when two calcining and two matting furnaces were erected, from which the first matte was shipped early in 1880. Since then, work has been carried on with such activity that the shipments of ore and matte for the first nine months of 1884 have averaged 2,600 tons of copper per month.

There are now in the district seven metallurgical establishments, containing collectively one hundred and twenty-seven jigs, sixty-five reverberatory, and two mechanical calciners, forty-four reverberatory matting furnaces, five water-jacket blast furnaces, and three Manhés converters. To these will shortly be added eighteen reverberatory calciners, six reverberatory matting furnaces, one water-jacket blast furnace, and three Manhés converters.

The different works in the district will then have the following aggregate daily capacity, viz.:

Concentrating	1,200	tons of ore.
Calcining	650	,,
Matting	675	,,
Converting	60	,,

If running on ores of the same grades as are now worked, the above capacity would give a production of 4,500 tons of copper per month, and 54,000 tons per year, an amount which Butte will, in all probability, produce in 1885.

Before attempting to estimate the cost of production, it is necessary to review the prices current in Butte for labour and supplies, and to sketch out the methods employed in treating the ores.

Prices.	$	
Common labour	3·00	per day.
Miners	3·50	,,
Timbermen	4·00	,,
Foreman	5·00 to 8·00	,,
Furnace hands	3·50 ,, 4·50	,,
Powder, No. 1 giant	0·30	per lb.
,, No. 2 ,, ...	0·26	,,
Fuze, double tape	1·00	per M.
Caps	0·90	per box.
Timber	22·00	per M.
Steel, ¾ and ⅞ Jessup	0·18	per lb.
Steel, 50 Black Diamond	0·13	,,
Iron, 4 cent rates.		
Coal	9·00	per ton.
Coke	20·00	,,
Wood	5·00	per cord.
Beef	0·10	per lb.
Flour	7·00	per barrel.
Butter	0·30	per lb.
Hay	17·00	per ton.
Oats	0·01¼	per lb.

MINING AND METALLURGY.

All the large mines have well-timbered two- or three-compartment shafts, and either now have or will soon obtain first-class hoisting-engines and good safety-cages.

None of the mines have any large flow of water, a small direct-action steam-pump proving sufficient to control the water in every instance.

Naturally enough, the different companies keep their business very much to themselves, and cannot be expected to furnish detailed expense accounts for publication; still, a careful examination of the works by any one familiar with mining and smelting under the conditions obtaining in the United States, reveals data sufficient to make possible an estimate of the cost of production with all necessary accuracy.

The cost of mining varies in proportion to the size of the vein and plant, and the facilities for working, much more than in accordance with the hardness of the rock, for the soft and easily-worked ground nearly always "creeps" and "swells," requiring heavy timbering and constant watching, while the harder and tougher ground "stands" with little timber and less care.

Mining, including development, timbering, hoisting, pumping, sorting, "top-work," superintendence, insurance, depreciation of plant, &c., costs from $2·50 to $4·50 per ton, averaging $3·50.

From the mines to their respective works the ore is carried in different ways—by the Utah and Northern Railway, by ropeways and horse trams, and by wagons, at costs varying from 15 cents to $1·00 per ton, and, when taking into consideration the quantities hauled at the respective weights, averaging 60 cents per ton.

On reaching the works, the third-class ore, which forms the greater part of the material handled, is treated by wet concentration. The ores are first broken by Blake crushers, then passed through one pair, and sometimes two pairs of Cornish rolls, sized in inclined revolving trommels and "gravity sizers," and then separated in two-, three- or four-compartment jigs. There is much difference of opinion as to the relative merits of side and bottom discharge-jigs; but, to judge from the work performed, there is little to choose between the two systems. To concentrate the slimes, one mill employs rotary buddles, two mills use Rittinger tables, and in two the current of slimes passes through large settling tanks, all the "settlings" being afterwards dried and smelted. All the new concentrating works, excepting those of the

Anaconda Mine, recrush the "seconds" and coarse tailings, have ample screening capacity, and are doing excellent work.

With increase of depth in the mines, the proportion of iron pyrites appears to increase, and as this cannot be separated from the richer ore by jigging, the resulting concentrates cannot be raised to a very high percentage of copper. At present from 1¾ ton to 2½ tons is all that can be thrown into one, and this product assays from 19 to 25 per cent. of copper. If ore from the deepest workings were treated by itself, the concentrates could not be profitably raised above 19 per cent., and there are indications that the value of the product will still further diminish in depth.

Upon the dumps of the different mines there are large accumulations of third-class ore awaiting treatment, one company having over 175,000 tons of this material on the surface. Hoisting large amounts of concentrating ore long before it can be treated, as has already been done, will undoubtedly prove a serious mistake. Not only will the oxidation and disintegration of the ores augment the loss in concentration, by greatly increasing the percentage of slimes, but the small amount of soluble copper salts always formed in Butte ores by a few months' exposure on the surface will be very destructive to screens, beds, and piping.

The cost of concentration in the several works differs greatly. Including power, superintendence, interest, insurance, repairs, depreciation of plant, &c., it runs from $1·00 to $2·00, averaging $1·50 per ton.

The concentrates are calcined or roasted in reverberatory furnaces, fired with fir or pine wood. The latest and best of these furnaces have four hearths, each 14 feet by 14 feet 6 inches in the clear, and desulphurize 11 tons in twenty-four hours. Two men are employed on each shift, and the consumption of wood under favourable circumstances does not exceed one-fifth of a cord per ton.

This work, however, is far above the average of the camp, and instead of calcining ores at a cost of $2·50 per ton as shown above, the expense often reaches $4·00 per ton, the general average being $3·00 per ton. Some of the works also practise heap-roasting for the first and second class, and are able to desulphurize a portion of the heaviest ores at a very low cost, but the amount handled in this manner is too small to have any appreciable effect upon the cost of production.

After calcining, the ores are cooled, mixed, and shovelled into the matting furnaces, the charges in the different works varying from 2¾ to 3½ tons. These furnaces are all of the ordinary reverberatory pattern, and smelt four to five charges per day, consuming about 7 tons of coal.

From $\frac{9}{10}$ to $1\frac{1}{2}$ per cent., averaging $1\frac{1}{4}$ per cent. of copper, is lost in the slags, which vary greatly in composition, although a point midway between a dibasic ($2ROSiO_2$) and a monobasic ($ROSiO_2$) silicate is generally aimed at. In one instance slags have been utilized in making large coarse bricks, which seem to answer very well for foundations and retaining walls.

The cost of matting, including superintendence, office expenses, repairs, stoppages, interest, insurance, and depreciation of plant, varies between $7·00 and $9·00, averaging $8·00 per ton.

Of the five water-jacket blast furnaces in the district, four are intended merely as substitutes for reverberatory matting furnaces, and only one of these is at present in operation. The fifth is part of a new plant employing the Manhés Bessemerizing process.

The works for the Manhés process contain six calciners, one brick machine, one water-jacket blast-furnace, and three converters. They are expected to handle 65 tons of ore daily, and, if successful, to effect a saving over the method now in general use of from $\frac{1}{3}$ to $\frac{1}{2}$ cent per lb. of refined copper.

The matte is crushed in Blake or Dodge crushers preparatory to sacking, and is sampled by taking a piece out of the top of each sack.

Sacks delivered at the works cost about 9 cents each, or $1·65 per ton of matte sacked. Crushing, cleaning, sacking, sampling, sewing, and loading on the cars for shipment costs $4\frac{1}{4}$ cents per sack. Power, wear and tear of breaker, elevators, &c., amounts to about 1 cent per sack, bringing the total cost to $2·65 per ton of matte for sacking (including sacks) and loading.

The railway charges from 25 to 50 cents per ton, according to distance, for "switching" cars from the several works to Butte station. This charge averages 40 cents per ton of matte.

Present freight rates from Butte station are:—

	$	
To New York	22·50	per ton of 2,000 lbs.
„ Liverpool	25·00	„ „
„ Baltimore	21·90	„ „

Charges for refining vary from $2\frac{1}{2}$ to 3 cents per lb. of refined copper, the latter being the quotation current in Baltimore. For round lots the average rate, $2\frac{3}{4}$ cents, is always obtainable, and covers all costs at the refining works, such as unloading, weighing, sampling, &c.

RECAPITULATION.

Cost of Ingot Copper produced from Butte City ores and delivered in New York.

		$		$
Mining 100 tons of ore (6 tons 1st class, 14 tons 2nd class, and 80 tons 3rd class)	at	3·50	per ton	350·00
Transporting same to works	„	0·60	„	60·00
Concentrating 80 tons 3rd class . . .	„	1·50	„	120·00
Crushing and handling 20 tons 1st and 2nd class	„	0·50	„	10·00
Calcining the same and 40 tons of concentrates	„	3·00	„	180·00
Matting 60 tons of 21 per cent. ore . .	„	8·00	„	480·00
Sacks, sacking, and loading 20 tons of matte	„	2·65	„	53·00
Switching charges on the same . . .	„	0·40	„	8·00
Freight to New York on 20 tons of 60 per cent. matte	„	22·50	„	450·00
Refining charges 24,000 lbs. of copper .	„	2¾ c.	per lb.	660·00
				$2,371·00

or 9·88 cents per lb.

CALCULATION of EXPENSES per lb. of COPPER.

	$
Mining	0·0146
Transporting to works	0·0025
Concentrating	0·0050
Crushing and handling 1st and 2nd class .	0·0004
Calcining	0·0075
Matting	0·0200
Sacking (including sacks) and loading . .	0·0022
Switching	0·0003
Freight to New York	0·0188
Refining	0·0275
	0·0988

The cost of 20 American or 16·827 English tons[1] of 60 per cent. copper regulus, delivered in Liverpool, would be $1,756, equal to £21 9*s.* 5*d.* per ton, or 7*s.* 2*d.* per unit of copper.

These are undoubtedly the lowest figures at which copper is now produced at Butte city, but it is possible that more experienced management at the works, and improved methods, under the strain of severe competition, could reduce the cost of refined copper from Butte, delivered at seaboard, to 9 cents per lb.

From the great variations in the expense of many items of the cost of production, it might be inferred that some one company possesses a much larger proportion of the conditions necessary for cheap production than any of the others, and thus be enabled to lay down ingot copper in Eastern markets at a cost much below the average figures given. This, however, is not the case, as no one of the mining and smelting companies combines all the elements of cheap production. For example, the entire product of one of the largest mines is saddled with a cost of $1·00 per ton for transportation to its works, while one of the smallest mines hauls its ore to the smelter for 15 cents per ton. Again, some of the companies are still able to bring their concentrates up to 25 per cent. of copper, but for various reasons their working expenses are much nearer to the highest than to the average figures given. Similar opposing conditions apply to many items other than those mentioned, and go far toward equalizing the cost of production at the different establishments.

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[1] An English ton of copper matte is 2,377 lbs.—D. W. B.

Railroad competition will probably diminish freights, greater experience and improved smelting facilities will decrease the metallurgical expenses; but, on the other hand, increased depth in the mines will undoubtedly augment the flow of water, and in various ways add to the cost of mining, and both the composition of the ores and the present development of the mines indicate clearly that depth will be accompanied by a decrease in the assay value of the ores.

Whether these changing conditions will exactly neutralize each other is a question at present unanswerable, but unless some marked changes occur, or important improvements are introduced, it is safe to assume that the cost of production will not, for a considerable time, differ greatly from the estimate herein given.

(*Paper No. 2076.*)

"Corrosion of Metals during Long Exposure in Sea-Water."[1]

By THOMAS ANDREWS, F.R.S.E., Assoc. M. Inst. C.E.

THE subject of the relative corrosibility of wrought-iron, steels and cast metal in sea-water is one of considerable practical importance.

In a former Paper[2] the Author endeavoured to investigate some of the galvanic aspects of the question; the research would however be incomplete without the additional gravimetric results extending over very long periods, recorded in the present communication, and there is ample room for further research in this direction.

The whole question of the employment of wrought-iron or steels for marine structural purposes, ought, apart from bias, to be regarded by the light of established data and experience, in a broad and comprehensive manner, as other considerations than that of corrosion are involved. At present the Author only wishes to record the results of experiments on the corrosion of various steels, wrought-iron and cast metals in sea-water, commenced in December 1880, and trusts that as a contribution of observed facts they may be acceptable to the Institution.

The difficulty connected with a research of this kind is very considerable, owing to the differences in the comparative results being frequently small; as, however, the utmost care was exercised in every detail, the records of the present memoir may be regarded as fairly satisfactory.

The researches of the late Dr. Crace Calvert point out the chemical causes inducing the ordinary corrosion of iron and steel.

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[1] Information on analogous subjects will be found on reference to the following recent Papers:—

"Corrosive Effects of Steel on Iron in Salt Water," by J. Farquharson, Transactions of the Institution of Naval Architects, March 30th, 1882.

"Experimental Research on the Electromotive Force from Difference of Potential during Diffusion in Tidal Streams," by Thos. Andrews. (Proceedings of the Royal Society of London, 1884, vol. xxxvii. p. 28.)

[2] Minutes of Proceedings Inst. C.E. vol. lxxvii. p. 323.

He thus writes: "Under the conditions described, pure and dry oxygen does not determine the oxidation of iron, that moist oxygen has only feeble action; dry or moist pure carbonic acid has no action, but that moist oxygen containing traces of carbonic acid acts most rapidly on iron, giving rise to protoxide of iron, then to carbonate of the same oxide, and last to a mixture of saline oxide, and hydrate of the sesquioxide of iron."

Previous to Dr. Calvert's experiments, Mr. C. von Hauer found that by passing a current of carbonic acid during several hours through water at the ordinary pressure of the atmosphere, in which very finely divided iron was suspended, such as is produced by heating to redness oxalate of protoxide of iron, or by reducing oxide of iron by hydrogen, the solution contained 0·091 per cent. of carbonate of protoxide. The researches of Mr. J. Y. Buchanan, during his extended voyages in different oceans, on the gases dissolved in sea-water at various depths, tend also to throw light on the subject of marine corrosion. From the researches of Mr. C. von Hauer, Dr. Calvert, and others, it may therefore be generally assumed that the corrosion of wrought-irons, steels, and metals in sea-water is due to the chemical influences of the saline constituents of the water, aided by the action of the contained carbonic acid gas, oxygen, or other gases; and corrosion is likewise further greatly increased, under certain circumstances, by galvanic effects arising from various causes. For the purposes of this Paper the Author's experiments on corrosive action may be roughly classified under the following heads:—

I. Simple corrosion, when bars or plates of the metals (wrought-iron, steel, &c.) of known composition and physical properties, were exposed singly in sea-water for various periods.

II. Galvanic corrosion between bars or plates of dissimilar metals (such as wrought-iron, steels, cast metals, &c.) connected together under equal conditions in circuit, and immersed in sea-water, the metals thus becoming galvanic elements after the manner of the voltaic cell. The results of this set of experiments indicate gravimetrically, that similar destructive forces in iron and steel structures are not inconsiderable.

III. Experiments on the electrolytic disintegration of the metals in sea-water long exposed under conditions stated, to constant electric currents of varied and known intensity, whereby the ordinary corrosive effects were proportionately increased.

Although the latter experiments constitute in one aspect a measure of the electric action applied, yet the relative percentages of corrosive decomposition noticed, afforded indication of what might occur in parts of iron and steel structures exposed accidentally to concentrated galvanic action of a similar character. The Author employs the words "simple" and "galvanic" corrosion in this Paper rather as descriptive than specific terms; but practically, the effects of simple corrosion are nearly always complicated by local galvanic action. It might be considered that the small differences in the composition of various irons and steels would not be capable of setting up any appreciable galvanic action when these metals are in contact, or of inducing much increased corrosion. These experiments show, however, that such is far from being the case, and the sum of the electric corrosive forces from various causes, obtaining in marine and other structures, is unfortunately a considerable factor of destruction. The experiments cannot afford absolute data, but as they have been conducted with the greatest care they may be regarded as quantitative indications of what occurs on the large scale.

The chemical composition of some of the iron and steel bars and plates employed in the experiments is given in the Appendix in the analyses on Tables I. and II., and the metals were taken from the Author's standard samples.

Wrought-iron No. 2 was made at the Author's works (the Wortley Ironworks) from selected clean scrap-iron. Cast metal No. 1 was a mixture of one-half of Lilleshall cold-blast No. 3, and one-half of hematite No. 3. Cast metal No. 2 was a mixture of one-half scrap metal, and one-half Sheepbridge No. 3.

The plates (Table II.) were manipulated in the ordinary manner, and were of different molecular structure to the bars.

The bars (Table III.) were purposely selected of a high tenacity as indicated by the tensile strain test.

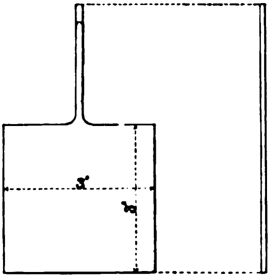
PART I.

SIMPLE CORROSION.

The wrought-iron, steel and cast metal bars used in the following experiments were carefully-prepared rods 7·5 millimetres in diameter, brightly polished, and of the chemical composition given in Table I.

The plates (polished bright on both sides and on all the edges) of the various metals, of the chemical compositions, &c., given in Table II., used in all the following experiments, were each exactly 3 inches square by $\frac{1}{8}$ inch thick, giving a total surface area of exposure of 19·5 square inches, including edges, the form being as shown in Fig. 1. The shank was connected with a wooden support (not touching the water) for maintaining the plates in a vertical position in the simple corrosion experiments, and in the galvanic corrosion experiments the shank was used for connecting the plates together in pairs, in circuit, by means of strong brass screw clips, as shown in Fig. 3. The whole of the weighings were made on a delicate chemical balance turning with $\frac{1}{200}$ grain. For the simple corrosion experiments in Table IV., the plates (one of each metal) were immersed for the periods stated, upright, in sea-water in a wooden trough of suitable size; the sea-water was changed monthly during the whole period of one hundred and fourteen weeks, and the loss in the interim from evaporation made good by regular addition of distilled water. In the following experiments on simple corrosion, the polished bars were carefully cleaned with soft chamois leather, dried at 212° Fahrenheit, and weighed.

Fig. 1.



Each bar was suspended horizontally in a separate glass vessel containing 7,000 fluid grains of filtered sea-water from Filey Bay.

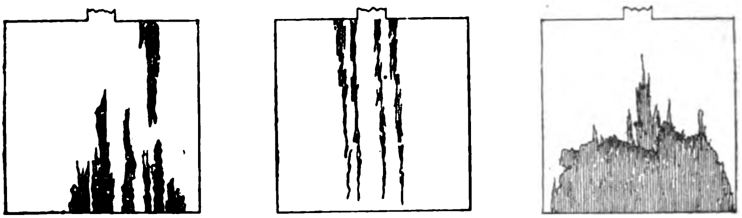
In twenty-four hours the wrought-iron was covered all over with small bubbles, the Bessemer steel and soft cast-steel bars remaining free from bubbles.

In four days from the commencement the bubbles had disappeared from the wrought-iron rod, and oxidation had commenced rapidly in this bar and in all the others, with the exception of puddled steel, which remained as yet quite bright and apparently little affected by the sea-water. On the following day oxidation seemed to be proceeding rapidly with all the samples, puddled steel included. Seven days from the commencement the whole of the sea-water solutions presented a yellowish opalescent appearance, which was most noticeable in that containing the soft cast-steel, and least so in the case of the wrought-iron and puddled steel. At the end of twenty-eight days the bars of wrought-iron, steel, &c., were removed from the sea-water, carefully washed and cleaned from adhering oxides with chamois leather, then dried at 212° Fahrenheit and weighed (Table IV.). In all the above samples the oxidation consisted of reddish yellow ferric oxide at the top of each bar, and of dark-green ferrous oxides on the under side. They were afterwards re-immersed in fresh sea-water for further oxidation, again withdrawn at the stated intervals, cleaned, dried, and weighed, with the results given in Table IV.

The plates, more especially the steel, when taken out after a total period of two years and ten weeks' exposure, emitted a very distinct odour of carburetted hydrogen, owing probably to the dissociation of the carbides of the steel from the chemical action of the sea-water. The Author desires also to direct attention to the progressively increasing rate of corrosion of the plates during the periods stated, the increased corrosion during the second year compared with the first one, amounting in some instances to above 50 per cent.

The totals in Table IV. show, as regards the "soft" steel plates, that the lower the percentage of combined carbon the less was the corrosion, the best scrap-iron No. 2 corroding during the period of one hundred and ten weeks much less than the steels for the same time. The wrought-iron No. 1 (which contained roughly about double the percentage of phosphorus and manganese) corroded more than the best scrap-iron; but less in the total period than any of the steels, with the exception of soft Bessemer. An excess of manganese in any of the metals is liable to produce increased corrosion, because it tends to induce local action, from its uneven distribution throughout the metals.

Figs. 2.



Soft Siemens-Martin Steel. Hard Bessemer Steel. Hard Cast Steel.

Discrimination is necessary in attempting to define the nature of the corrosion proceeding in any structure; effects which may appear due to simple corrosion are frequently intensified by galvanic action arising from difference of the composition, or physical properties, in the metal itself, the action of the sea-water thereon producing local action, which is also frequently induced by minute portions of magnetic oxide scale on the surface of iron or steel. This scale is capable of becoming an abundant source of galvanic mischief.

Figs. 2, taken at the time, give the appearance presented by these plates during the early commencement of simple corrosion, the lightly shaded portions showing the parts first oxidized, which had the greenish appearance of ferrous oxide. It will also be noticed that corrosion started from a number of centres or nuclei, and this is confirmed by the appearance of most of the metals after long exposure to galvanic action of varied intensity in sea-water (Plate 4).

PART II.

GALVANIC CORROSION.

1. *Experiments on Bars of Wrought-Iron and Steels in Galvanic Connection, immersed in Sea-Water.*

The following gravimetrical experiments tend to confirm the results obtained by the galvanometer observations relating to changes of electro-chemical position between the wrought-iron and steels, &c., in sea-water.[1]

The metals used were carefully prepared rods 7·5 millimetres in diameter, and of the chemical composition given in Table I.

In these experiments the polished bars of iron, steel, &c., were cleaned, dried at 212° Fahrenheit, then carefully weighed on a delicate chemical balance, and afterwards suspended horizontally in couples, a bar of wrought-iron being connected with a bar of steel, in sea-water from Filey Bay, contained in large glass beakers.

The bars were firmly connected in circuit at equal distances apart in each case, and good contact was maintained. Within five or ten minutes of immersion, fine streaks and filaments of pale coloured oxides of iron began to exude from both the iron and steel bars. In twelve hours the sea-waters in which the bars were immersed presented a pale straw-colour, being slightly turbid with peroxide of iron, and the bars were quite covered over with a coating of peroxide. At the end of seven days there appeared to be much more deposit of peroxide on the wrought-iron bars in each case than on the steel bars, and there was a considerable deposit of peroxide at the bottom of each beaker containing them. At the termination of the periods stated in the tables, the bars were removed, washed, polished with soft wash leather, and dried at 212° Fahrenheit, and weighed on the balance.

The general results obtained are recorded on Table V. On comparing these with those obtained from simple corrosion only

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[1] Minutes of Proceedings Inst. C.E. vol. lxxvii. p. 323.

(Table IV.), it was noticed that the total corrosion taking place was increased by the galvanic action. On reference to Table V. the loss in weight of the steels was found to be less than that taking place in the wrought-iron after only seven days' exposure, and in some cases after twenty-eight days, though the reverse was the case during exposure for the total period, as at the end of one hundred and twelve days the loss was greater in the case of the steels, indicating that a reversal of electro-chemical position had apparently taken place. In the case of simple corrosion of bars (Table IV.) without galvanic action, the destruction was not so great in the wrought-iron as in the steels. The interchanges of electro-chemical position between these metals in sea-water appear to exercise a considerable influence, and will doubtless account for some of the changes observed in the relative rates of corrosion in some of the metals. It is not easy to say to what extent the evolved gases on the surface of the steels affect these electrical reactions.

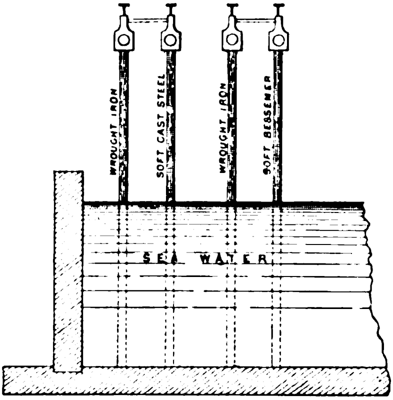
The gravimetric results appear therefore to confirm the observations on the interchanges of the relative electro-chemical position of the metals, made in the galvanometer experiments of the former Paper.

2. *Experiments on Plates of Wrought-Iron, Steels, &c., in Galvanic Connection immersed in Sea-Water.*

The experiments were conducted in the following manner:—at the commencement, the polished plates were dried at 212° Fahrenheit and weighed on the balance, and a bright plate of each of the metals (Fig. 1) was connected by strong brass screw-clips and copper wire 0·105 inch in diameter, with a plate of bright wrought-iron of the same size at distances of ⅝-inch apart in each case. The wrought-iron plates exhibited the same chemical composition, &c., and were portions cut from one larger standard plate. The whole were immersed in sea-water in a wooden trough, and the sea-water was changed monthly during the periods of this investigation. Good contact between the metals was maintained throughout. Loss from evaporation was prevented by frequently filling up to the standard mark with distilled water. At the periods stated on Table VI. each pair of plates was carefully attached to a delicate galvanometer of known constants for one day, and the electro-chemical position of the metals and the electromotive force was determined, the resistance in each case being also ascertained. The same conditions obtained throughout, so that an exact comparison could be made between the various metals. At the end of the periods given, the plates were removed, washed, and polished with soft chamois leather, dried at 212° Fahrenheit, and weighed with the results on Table VI., then again connected and re-immersed in the sea-water for the further observation.

The whole of the plates, when taken out of the sea-water after the long exposure, were found to be completely covered with soft slimy oxides of iron, easily removable, the upper half of each plate presenting the characteristic reddish yellow colour of rust. On the lower parts of the plates the deposit was black, and a considerable black corrosive sediment was found at the bottom of the tanks. A portion of this black deposit, a product of corrosion found at the bottom of the cells, was submitted for analysis to Mr. A. H. Allen, the borough analyst of Sheffield. The deposit from the "soft" Bessemer steel and "hard" Bessemer steel cells only was analysed. It is difficult to give the exact composition of the substance as originally formed, as it so rapidly undergoes oxidation. Mr. Allen remarks in his report—"The iron is certainly partly in combination with sulphur, but there is not sufficient sulphur present to combine with the whole of it. A portion of the iron may also be combined with carbon, but I fancy the carbon largely exists in combination with hydrogen and probably oxygen, to form a body of the humus type. Assuming this to be the case, and regarding the phosphoric acid and silica simply as accidental admixtures, the dry deposit must have somewhat the following composition:—

FIG. 3.



Section of Wood Tank.

	Deposit from the bottom of the "Soft" Bessemer Steel cell.	Deposit from the bottom of the "Hard" Bessemer Steel cell.
	Percentage of dried deposit.	
Iron	51·8	50·5
Sulphur	11·1	11·1
Carbon	6·0	7·0
Oxygen and hydrogen .	26·6	27·5
Phosphoric acid and silica	4·5	3·9

"An attempt to estimate the hydrogen and oxygen in the 'hard' deposit gave 22·1 per cent., so that the proportions present are at any rate very considerable. Much may exist as actual water of composition, but how much is present in this form is quite uncertain."

PART III.

ELECTROLYTIC DISINTEGRATION OF THE METALS IN SEA-WATER LONG EXPOSED UNDER CONDITIONS STATED, TO CONSTANT ELECTRIC CURRENTS OF VARIED AND KNOWN INTENSITY.

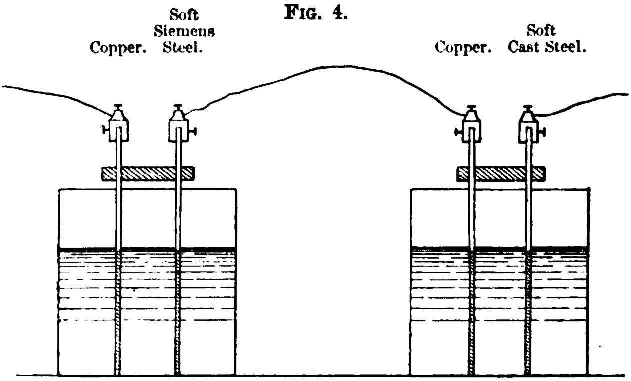
Set 1.—Plates of steel covered with scale and bright plates of the same steels, &c., after being dried at 212° Fahrenheit and weighed, were arranged in galvanic connection at distances of ½-inch apart, and immersed in sea-water in an arrangement of cells forming a voltaic series similar to Fig. 4. A regular fresh supply of sea-water was maintained monthly in each case during the experiments. The gravimetric results are given on Table VII.

The galvanic action to which the metals were thus constantly exposed was also ascertained from time to time.

Set 2.—Bright steel, wrought iron, &c., plates after being dried at 212° Fahrenheit and weighed, were arranged each in connection at distances of ½-inch apart, with a bright copper plate, the whole forming a completely connected voltaic series in sea-water, in an arrangement of cells (Fig. 4). A constant supply of sea-water was maintained during the experiment, the water being changed monthly. The corrosive results are given in Table VII.

Set 3.—In the following experiments the bright steel, &c., plates after having been dried at 212° Fahrenheit and weighed, were arranged each in connection at ½-inch apart, with a bright wrought-iron plate, of equal dimensions, in sea-water in a similar arrangement of cells to Fig. 4. This voltaic series of plates was then subjected to the action of a constant current of electricity, which was steadily maintained by alternately using two batteries for sixteen weeks. By the preceding arrangements of the plates, each metal was thus exposed under equal conditions to the action of the same strength of current stated in Table VII. In these experiments during the first part of the time, the direction of the current was arranged so that the iron plates formed the anode metals. The direction of the current was reversed during the latter part, the steel, &c., plates then constituting the anode metals. This alternation in the direction of the current was made to approximate in a highly intensified manner, to effects which might possibly be produced on structures by the interchanges of electro-chemical positions between the metals, observed electrically as stated in the former Paper, and gravimetrically in the present Paper in Table V., or from other accidental causes. The results are given in Table VII.

FIG. 4.



REMARKS ON TABLE VII.

Sets 1 and 2 show the relative greater corrosion induced by the increased galvanic action to which the metals were exposed. Set 3 shows the relatively greater corrosion induced by the largely increased galvanic action to which the metals were exposed for the period of time stated.

Set 1.—A reference to Table VII., set 1, period 1, indicates that an exposure to an average electromotive force of about 0·038 volt in sea-water for sixteen weeks was productive of less corrosion in the wrought iron No. 1 than in any of the steels. A more prolonged exposure of fifty-two weeks to a similar average electromotive force of about 0·030 volt, set 1, period 2, appeared to reverse this result in favour of the steels, with the exception of the soft cast steel and hard Bessemer.

Set 2, period 1.—In the case of galvanic action between copper and wrought iron, the wrought iron under these conditions corroded more than most of the steels, during sixteen weeks' exposure to an average electromotive force of about 0·093 volt; during the second period of fifty-two weeks, the loss in all the metals considerably increased, and in the case of the "soft" cast steel exceeded that of the iron. When, however, the metals were under the action of a very much higher electromotive force (3·86 volts) as in set 3, the wrought iron had the advantage over all the steels, with the exception of "hard" Bessemer, from which it would appear that wrought iron is less acted upon in sea-water by a large electromotive force than steels. It should be remembered, however, that all the results on Table VII. are of a much more intensified character than may ordinarily be expected to occur.

On the completion of the experiments of Table VII., set 3, the plates were found covered with a black carbonaceous-looking deposit, and, in addition, on the exposed side of the kathode plates were found innumerable fine acicular metallic crystals, unfortunately somewhat rusted, the result of the electrolytic decomposition of the anode plates being deposited in this interesting form on the kathode plates. These crystals were carefully removed, washed, dried between folds of blotting paper, and submitted for analysis to Mr. A. H. Allen, whose report was as follows:—

"I have carefully analysed the crystals of iron deposited by electrolysis in sea-water, and find them to be practically pure iron, to a great extent rusted. There are none of the impurities of ordinary iron present, with the exception of sulphur, which existed to the extent of 0·021 per cent. on the original sample after drying. Carbon, phosphorus, silicon, and manganese, were proved to be absent. The amount of iron in the dried rusty crystals was 83 per cent., the remainder being oxygen, water of constitution, salt, &c."

The accompanying illustrations, Plate 4, prepared from ten photographs of the plates from Table VII., set 1, period 1, and set 3, show the relative corrosive effects produced on the various metals under the varied conditions of the experiments. A careful examination of these will be found of interest, demonstrating as they do many curious features of the galvanic corrosion of metals in sea-water. The appearance of the corroded plates indicates that, in the case of the "soft" and some other steels, the work of destruction emanated from a number of nuclei or centres. These metals (with the exception of the soft cast steel, which was, perhaps, least so) were generally considerably indented and honeycombed locally. They exhibit also numerous long openings, or gaps, near the bottom of the plates. Many of these centres of corrosion were on both sides of the plates, and nearly penetrated through some of the steels. The corrosion in the case of the wrought iron seemed more uniformly distributed over the surface, and was of a less deeply indented character, the fibre of the iron being clearly manifested. A microscopic examination of the interior of these large deep corrosion cavities in the steels, &c., with a good light reflected therein, reveals the mode in which the interior structure of the metal was attacked by the corrosive action of the sea-water under the conditions recorded. An attempt was made to obtain a greatly enlarged photograph of the interior of one of these corrosive craters, but was not successful owing to the difficulty of bringing all the parts in focus.

The experiments in this Paper indicate the nature of some of the destructive forces at work in iron or steel vessels, and all kinds of marine structures which, although shielded by protective paints and compositions, are still not unfrequently accidentally exposed to electric destructive agencies by no means inconsiderable. It is also not easy to estimate to what extent the stability of iron or steel bridges may have been effected by corrosive galvanic action.[1]

GENERAL REMARKS.

Some general indications, the outcome of these numerous experiments, may now be briefly stated.

The Author trusts that this investigation may be of practical utility, owing to the prolonged periods over which the observations have extended, and the great care exercised in endeavouring to obtain accurate results. The present communication is not intended to be controversial; but is simply a record of observed facts. The experiments on simple corrosion, Table IV., where bars of wrought iron, steels, &c., were exposed singly and separately, without liability to galvanic action other than local, to the action of sea-water for the various periods named, indicate a greater tendency to corrosion on the part of all the various steels than the wrought iron. This remark also applies to the comparative behaviour of the steel and best wrought-iron plates in the same Table. A reason for the steels corroding more than the wrought iron, in the case of simple corrosion, may perhaps be that the internal structure of steels is complex, and sometimes may exhibit several species of crystalline carbides of varying composition permeating the whole.[1] This would of itself constitute a local source of internal galvanic disintegration. The varying electro-chemical positions assumed by the steels and wrought iron, observed in these and the Author's former experiments, is also of considerable interest bearing on the previous suggestion.

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[1] Minutes of Proceedings Inst. C.E. vol. lxv. p. 113.

The result of the gravimetric experiments in this Paper, both on simple corrosion (Table IV.), and galvanic corrosion (Tables V. and VI.), which are the nearest approximation to what occurs in actual experience, extending over several years, in the course of which three different samples of wrought iron and various steels were employed, of the compositions described in this and the former Paper, and which were manipulated in the three distinct forms of drawn rods $\frac{297}{1000}$ inch in diameter, rolled bars about 3 inches in diameter, and rolled plates, together with the electrical experiments in the former Paper, concur in indicating generally less liability to corrosion, on the part of the wrought irons employed than in the case of the steels. It is difficult to form an accurate prognosis of the ultimate practical issue of the relative corrosibility of the metals. Limited to the question of corrosion only, it may, however, be surmised that a body possessing a fine crystalline texture like steel, and having a complex chemical composition, would be ultimately more liable to ordinary corrosive disintegration than a fibrous substance such as wrought iron. The tendency to increased loss during two years and ten weeks, by simple corrosion (Table IV.), and during the same period of galvanic corrosion (Tables V. and VI.) in the "soft" steels, in proportion as the percentage of combined carbon was greater, was an interesting experimental result tending to some extent to confirm this view. Prolonged actual experience, the true exponent of experimental work, may probably also confirm the above surmise. It may be possible by using wrought irons of other composition to obtain reverse results; this, however, would form a subject for further experimentation.

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[1] The appearances of the first commencement of corrosive action (Figs. 2) and at the termination (Plate 4) confirm this view. See also a paper by Mr. J. Spear Parker, on "The varying conditions of Carbon in Steel" ('Chemical News,' vol. xlii., 1880, p. 88); and also the research "On the Cellular Structure of Steel," by Messrs. Osmond and Werth, of the Creusot Works, recently communicated to the French Academy of Sciences.

From the preceding experiments it will be seen that both the simple and galvanic corrosion of all the metals in sea-water is considerable, though galvanic action would appear to be reduced in course of time, owing to the partial protection of the rust, and the singularly varying interchanges of electro-chemical position assumed by the steels and wrought iron under observation in the former Paper. The difference in the results obtained under the heads of simple and galvanic corrosion, show the importance of guarding against accidental galvanic action in structures from similar causes. In the construction of marine work it is of course always desirable, in order to reduce internal causes of disintegration, to endeavour to have the bars, plates, rivets, bolts, as near as practicable, of a similar material, temper, and composition, &c. So far as the question only of corrosion is concerned, the behaviour of neither iron or steel was quite as satisfactory as could be desired, and there is perhaps an opening for a more suitable and permanent metal in this respect.

The experiments are far from being as exhaustive or complete as the Author could wish; they should, however, be considered in connection with the former Paper "On Galvanic Action between Wrought Iron, Cast Metals, and Steels, during long exposure in sea-water."

The Paper is accompanied by several photographs and diagrams, from which Plate 4 and the figures in the text have been prepared.

APPENDIX.

TABLE I.—CHEMICAL ANALYSIS of BARS USED in the FOLLOWING GRAVIMETRIC EXPERIMENTS.

Description.	Graphitic Carbon.	Combined Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Tungsten.	Iron (by difference).	Total.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Soft Siemens-Martin steel	..	..	..	..	..	..	..	..	..
Wrought iron	..	trace	0·221	none	0·239	0·071	..	99·466	100·000
Soft cast steel	..	0·570	0 032	trace	0·066	0·147	..	99·185	100·000
Bessemer steel	..	0·550	none	0·032	0·175	0·216	..	99·027	100·000
Puddled steel	..	0·440	0·144	0·048	0·149	trace	..	99·219	100·000
Puddled steel (chilled) .	..	0·490	0·140	0·004	0·073	0·215	..	99·078	100·000
Hard cast steel	..	1·600[1]	0·145	0·002	0·025	0·183	..	98·045	100·000
Cast metal .	2·400	1·000[1]	0·570	0·140	0·580	0·860	..	94·450	100·000
Tungsten steel	..	1·750[1]	0·135	0·069	0·139	0·720	9·270	87·917	100·000

[1] By combustion.

TABLE II.—CHEMICAL ANALYSIS of the WROUGHT IRON, STEEL, and CAST METAL PLATES.

Description.	Graphitic Carbon.	Combined Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Iron (by difference).	Total.
	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Wrought iron No. 1	..	trace	0·206	0·024	0·454	0·396	98·920	100·000
„ No. 2 (Wortley Best Scrap) . .	..	none	0·392	0·034	0·270	0·194	99·110	100·000
Soft Bessemer steel . . .	..	0·150	0·015	0·111	0 064	0·540	99·120	100·000
Soft Siemens-Martin steel .	..	0·170	0·071	0·117	0·077	0·627	98·938	100·000
Soft cast steel .	..	0·460	0·074	0·025	0·210	0·184	99·047	100·000
Hard Bessemer steel . . .	..	0·510	0·068	0·113	0·087	1·153	98·069	100·000
Hard Siemens-Martin steel .	..	0·720	0·080	0·102	0·143	1·239	97·716	100·000
Hard cast steel	..	1·407[1]	0·121	0·056	0·080	0·360	97·976	100·000
Cast metal No. 1	1·500	2·010[1]	0·410	0·250	0·450	0·650	94·730	100·000
„ No. 2	2·620	0·670[1]	1·940	0·090	0·950	0·520	93·210	100·000

[1] By combustion.

TABLE III.—PHYSICAL PROPERTIES of the BARS.

Description.	Original.		Ultimate Stress.		Fractured.				Stress per Square Inch of Fractured Area.	Extension in 10 inches.		Appearance of Fracture.
	Size.	Area.	Total.	Per Square Inch of Original Area.	Size.	Area.	Difference.			Inch.	Per cent.	
							Area.	Per cent				
	Inch.	Sq. inch.	Lbs.	Lbs. Tons.	Inch.	Sq. inch.			Lbs.			Per cent.
Tungsten steel .	0·300	0·0700	12,561	179,443=80·1	0·270	0·0570	0·0130	18·6	220,368	0·73	7·3	{ 10 silky; { 90 granular.
Hard cast steel .	0 298	0·0697	10,967	157,316=70·2	0·289	0·0656	0·0041	5·8	167,179	0·12	1·2	100 granular.
Bessemer steel .	0·297	0·0693	9,851	142,150=63·4	0·275	0·0594	0·0099	14·2	165,841	0·16	1·6	100 granular.
Puddled steel .	0·296	0·0688	7,180	104,361=46·6	0·257	0·0518	0·0170	24·7	138,610	0·27	2·7	100 silky.
Puddled steel (chilled) . .	0·298	0·0697	6,322	90,703=40·5	0·295	0·0683	0·0014	2·0	92,562	0·07	0·7	{ 35 silky; { 65 granular.
Wrought iron .	0·296	0·0688	6,028	87,618=39·1	0·284	0·0633	0·0055	7·9	95,229	0·11	1·1	100 fibrous.
Soft Siemens-Martin steel . .	0·380	0·1130	8,328	73,699=32·9	0·250	0·0490	0·0640	56·6	169,959	1·97	19·7	100 silky.
Cast metal . .	0·293	0·0674	1,436	21,305= 9·6	0·293	0·0674	0·0000	0·0	21,305	0·00	0·0	{100 granular { (mottled).

TABLE IV.—SIMPLE CORROSION.

Description.	Simple Corrosion of Bars.				Simple Corrosion of Plates.				
		First period.	Second period.	Total period.		First period.	Second period.	Third period.	Total period.
						Loss per Square foot of Surface.			
	Combined Carbon (Table I).	Loss in weight of bars exposed singly in Sea-water for 4 weeks.	Loss in weight of bars exposed singly in Sea-water for 16 weeks.	Loss in weight of bars exposed singly in Sea-water for 20 weeks.	Combined Carbon (Table III).	Bright plates exposed singly in Sea-water for 4 weeks.	Bright plates exposed singly in Sea-water for 56 weeks.	Bright plates exposed singly in Sea-water for 54 weeks.	Bright plates exposed singly in Sea-water for 114 weeks.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Grains.	Grains.	Grains.	Grains.
Wrought iron	trace	0·22	1·00	1·22	..	..	..	..	..
Wrought iron No. 1	..	..	..	..	trace	34·40	114·68	169·70	318·78
Wrought iron No. 2 (Wortley Best scrap)	..	..	..	..	none	..	97·99	139·27	..
Soft Bessemer steel . . .	..	..	..	..	0·150	34·56	108·85	158·18	301 59
Soft Siemens-Martin steel .	..	..	..	..	0·170	40·00	125 83	155·00	320·83
Soft cast steel	0·570	0·27	..	..	0·460	35·76	148·65	227·74	412·15
Bessemer steel	0·550	0·29	1·14	1·43	..	..	..	..	..
Hard Bessemer steel . . .	..	..	..	..	0·510	38·96	134·92	199·68	373·56
Hard Siemens-Martin steel .	..	..	..	..	0·720	34·24	122·14	173·24	329·62
Hard cast steel	1·600	0·35	1·26	1·61	1·407	39·68	139·57	184·54	363·79
Puddled steel	0·440	0·37	..	..	..	..	..	..	..
Puddled steel (chilled) . .	0·490	0·40	..	..	..	..	..	..	..
Tungsten steel	1·750	0·30	0·88	1·18	..	..	..	..	..
Cast metal No. 1	..	..	..	..	2·010	..	160·62	254·25	..
„ No. 2	..	..	..	..	0·670	..	182·70	172·73	..
„ No. 3	1·000	0·38	..	..	..	..	..	..	..

TABLE V.—GALVANIC CORROSION of BARS.

Description.	Combined Carbon.	First period.			Second period.			Third period.			Total period.		
		Progress of galvanic corrosion during only 7 days.			Progress of galvanic corrosion in 28 days.			Progress of galvanic corrosion in 112 days.			Progress of galvanic corrosion in 147 days.		
		Loss in weight of the bars connected with a wrought-iron bar exposed to the action of Sea-water for 7 days.	Loss in weight of the wrought-iron bars connected with the various bars of steel.	Total loss in weight for both wrought-iron and steel bars.	Loss in weight of the steel bars after exposure to the action of Sea-water for 28 days, connected with a wrought-iron bar.	Loss in weight of the wrought-iron bars which formed one element connected with the various bars of steel, &c.	Total loss in weight on both the wrought-iron and steel bars in this experiment.	Loss in weight of the steel bars connected with wrought-iron bars after immersion in Sea-water for 112 days.	Loss in weight of the wrought-iron bars forming one element connected with the various steels.	Total loss in weight on both the wrought-iron and steel bars in this experiment.	Loss in weight of the steel bars connected with wrought-iron bars after immersion in Sea-water for 147 days.	Loss in weight of the wrought-iron bars forming one element connected with the various steels.	Total loss in weight on both the wrought-iron and steel bars in these experiments.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Soft cast steel	0·570	0·09	0·07	0·16	0·43	0·22	0·65	1·19	0·79	1·98	1·71	1·08	2·79
Bessemer steel	0·550	0·06	0·13	0·19	0·23	0·32	0·55	1·21	1·08	2·29	1·50	1·53	3·03
Puddled steel	0·440	0·05	0·11	0·16	0·34	0·36	0·70	1·54	0·87	2·41	1·93	1·31	3·27
Puddled steel (chilled)	0·490	0·05	0·10	0·15	0·33	0·37	0·70	1·23	0·98	2·21	1·61	1·45	3·06
Hard cast steel	1·600	0·06	0·12	0·18	0·45	0·19	0·64	2·46	0·55	3·01	2·97	0·86	3·83
Tungsten steel	1·750	..	..	..	0·17	0·45	0·62	0·27	2·17	2·44	..	..	..
Cast metal	1·000	0·05	0·13	0·18	0·38	0·39	0·77	1·56	1·41	2·97	1·99	1·93	3·92

TABLE VI.—CORROSION of WROUGHT-IRON, STEEL and CAST-METAL PLATES, IMMERSED in SEA-WATER in GALVANIC CONNECTION.

Description.	Combined Carbon.	Loss per Square foot of Surface.							Electromotive Force in Volts and Electro-Chemical positions of the Metals during First and Second Periods.[1]		
		Corrosion during 4 weeks.	First period. Corrosion during 56 weeks.		Second period. Corrosion during 54 weeks.		Total period. Corrosion during 110 weeks.				
		Bright steel, &c., plates in galvanic circuit with plates of the same metal but covered with scale (Magnetic Oxide).	Division 1. Bright steel, &c., plates in galvanic circuit with wrought-iron plates	Division 2. Wrought-iron plate connected with the various steel, &c., plates.	Division 1. Bright steel, &c., plates in galvanic circuit with wrought-iron plates.	Division 2. Wrought-iron plate connected with the various steel, &c., plates.	Division 1. Bright steel, &c., plates in galvanic circuit with wrought-iron plates.	Division 2. Wrought-iron plate connected with the various steel, &c., plates.	42 weeks from commencement.	52 weeks from commencement.	101 weeks from commencement.
	Per cent.	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.			
Wrought iron No. 1	trace	31·12	..	..	..	..	..	..	..	..	..
Wrought iron No. 2 (Wortley Best scrap)	none	..	..	..	..	..	..	..	..	..	..
Soft Bessemer steel	0·150	28·00	196·80	147·54	329·06	256·39	525·86	403·93	0·001 P	0·0004 P	0·002 N
Soft Siemens-Martin steel	0·170	27·20	200·71	133·81	326·70	219·91	527·41	353·72	0·0004 N	0·002 N	0·006 N
Soft cast steel . .	0·460	26·56	203·08	136·98	332·75	265·40	535·83	402·38	0·0004 P	0·001 N	0·0004 N
Hard Bessemer steel	0·510	44·16	184·60	154·34	352·25	263·41	536·94	417·75	0·0004 P	No E.M.F.	E.M.F. very feeble (Steel N)
Hard Siemens-Martin steel . . .	0·720	35·84	146·88	150·57	316·43	268·43	463·31	419·00	0·004 N	No E.M.F.	0·0004 P
Cast metal No. 1 .	2·010	36·56	226·63	105·08	303·14	232·39	529·77	337·47	0·004 P	0·009 P	0·002 N
,, No. 2 .	0·670	..	178·78	139·50	271·75	245·69	450·53	385·19	0·001 N	0·003 P	0·004 P

[1] After the long exposures it will be seen that the galvanic action was comparatively small.

Remarks.—Attention is called to the progressively increasing rate of corrosion of the plates during the periods stated.

The plates when taken out after a total period of two years and ten weeks' exposure emitted an odour of carburretted hydrogen similar to that noticed in the simple corrosion experiments on Table IV. The results on Table VI. show considerably less tendency to corrosion on the part of the wrought iron than any of the steels, the advantage in favour of the iron as compared with the soft steels, amounting roughly to 25 per cent. and upwards, for the period of two years and ten weeks, under the conditions stated. On comparing the results of simple corrosion, Table IV., with the observations on Table VI., it will also be seen that the galvanic action between the wrought iron and steels induced a largely increased total corrosion in the several metals. An indication of the E.M.F., which is of course much higher nearer the commencement, will be found on reference to the former Paper. Minutes of Proceedings Inst. C.E. vol. lxxvii. p. 323.

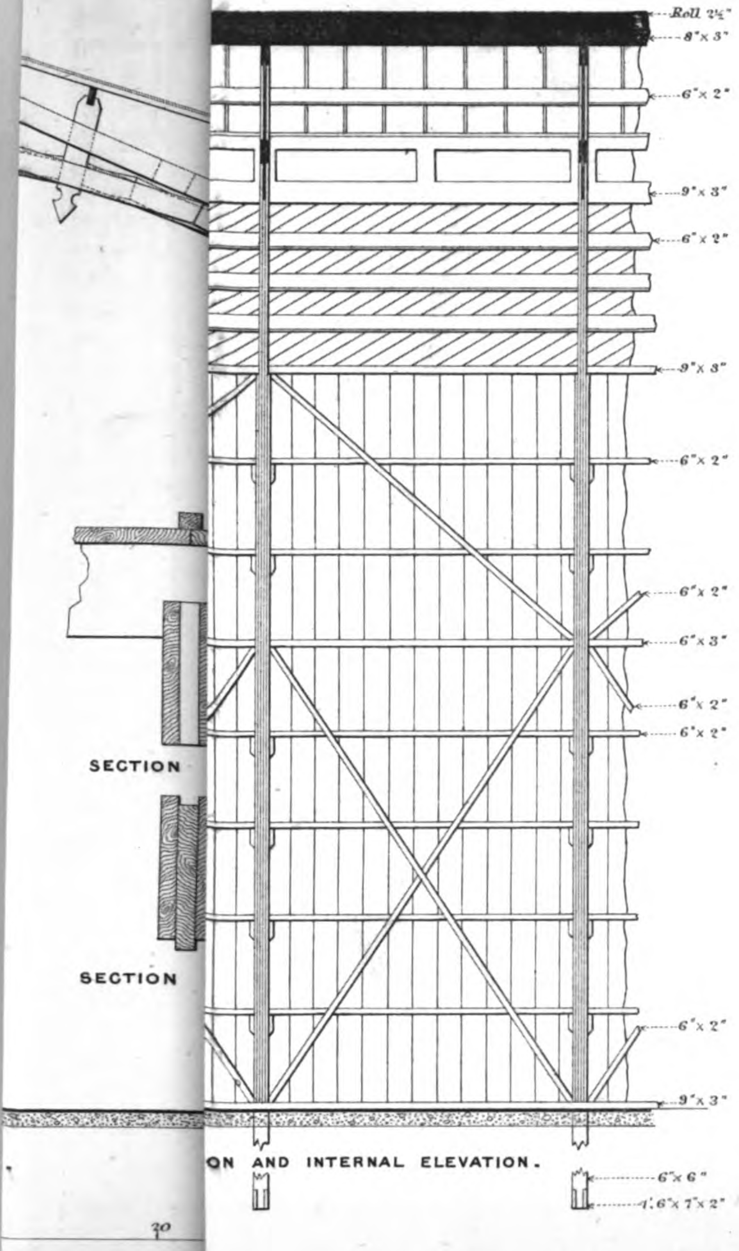
TABLE VII. (Plate 4).

Description.	Combined Carbon.	Set 1.							Set 2.							Set 3.	
		Period 1.			Period 2.			Total period.	Period 1.			Period 2.			Total period.		
		Column 1.	Column 2.	Column 3.	Column 1.	Column 2.	Column 3.		Column 1.	Column 2.	Column 3.	Column 1.	Column 2.	Column 3.		Column 1.	Column 2.
		Loss per square foot of surface of bright steel, &c., plates after exposure in Sea-water for 16 weeks to E.M.F. in column 3.	Time from commencement of experiment.	E.M.F. in Volt.	Loss per square foot of surface of bright steel, &c., plates after exposure in Sea-water for 52 weeks to E.M.F. in column 3.	Time from commencement of experiment.	E.M.F. in Volt.	Loss per square foot of surface of bright steel, &c., plates after exposure in Sea-water for 68 weeks to E.M.F. stated.	Loss per square foot of surface of the steel, &c., plates exposed in Sea-water for 16 weeks to E.M.F. in col. 3.	Time from commencement of experiment.	E.M.F. in Volt.	Loss per square foot of surface of the steel, &c., plates exposed in Sea-water for 52 weeks to E.M.F. in col. 3.	Time from commencement of experiment.	E.M.F. in Volt.	Loss per square foot of surface of the steel, &c., plates exposed in Sea-water for 68 weeks to E.M.F. stated.	Loss per square foot of surface of the plates exposed in Sea-water to E.M.F. in column 2 for 16 weeks.	Average E.M.F. to which the metals were exposed for 16 weeks.
	Per cent.	Grains.	Hour.	0·227	Grains.	Days.	0·054	Grains.	Grains.	Hour.	0·849	Grains.	Days.		Grains.	Grains.	
Wrought iron No. 1	trace	113·84	1	0·149	364·58	45	0·028	478·42	243·68	1	0·434	517·07	114	0·091	760·75	1324·88	During about first half of period about 1·17 volt. During about second half of period about 3·86 volts
„ No. 2 (Wortley Best scrap)	none		2	0·168		144	0·028			2	0·247		147	0·101			
			2½	0·186	394·19	151	0·037			3	0·191	534·94	151	0·091			
			24	0·186		155	0·046			24	0·130		155	0·072			
			Days.							Days.							
Soft Bessemer steel	0·150	127·20	37	0·072	337·26	159	0·028	464·46	221·28	2	0·168	382·82	177	0·037	604·10	1351·04	
			68	0·054		208	0·019			3	0·149		235	0·046			
Soft Siemens-Martin steel	0·170	157·36	88	0·037	208·39	239	0·028	365·75	159·28	4	0·149	497·72	238	0·072	657·00	1343·92	
			91	0·028		242	0·019			5	0·149		244	0·072			
Soft cast steel	0·460	173·76	108	0·019	405·34	248	0·028	579·10	234·56	6	0·130	552·66	255	0·081	787·22	1396·32	
			112	0·019		259	0·019			7	0·111		272	0·072			
Hard Bessemer steel	0·510	129·28		Average E.M.F. 0·038 Volt.	409·40	275	0·019	538·68	238·80	15	0·130	524·60	275	0·072	763·40	1079·28	
						312	0·034			16	0·072		297	0·154			
Hard Siemens Martin steel	0·720	164·56			377·65	316	0·043	542·21	252·32	18	0·072	523·35	300	0·128	775·67	1385·28	
						329	0·028			46	0·081		308	0·165			
Hard cast steel	1·407					347	0·022		261·84	53	0·081		312	0·149		1602·00	
						367	0·028			60	0·081		364	0·119			
Cast metal No. 1	2·010	184·88			354·90		Average E.M.F. 0·030 Volt.	539·78	263·60	63	0·081	570·68		Average E.M.F. 0·095 Volt.	834·28		
										96	0·111						
										112	0·054						
											Average E.M.F. 0·093 Volt.						

TIMBER

PLATE. 5.

DESIGNED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SECTION
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20

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THOs KELL & SON, LITH. 40, KING St COVENT GARDEN.

(*Paper No. 2097.*)

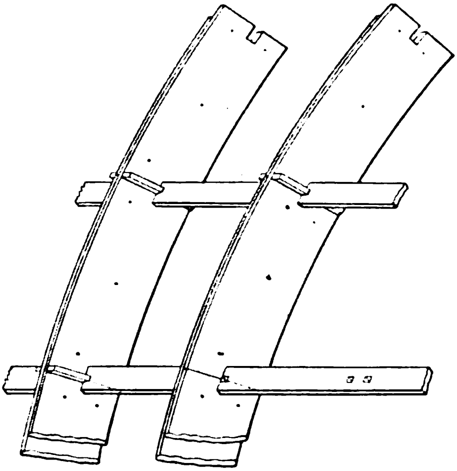
"The Semicircular Timber Roof-Truss Designed by the late Captain F. Fowke, R.E."

By Gilbert Richard Redgrave, Assoc. Inst. C.E.

The composite roof-truss devised by the late Captain Fowke, and extensively employed in various buildings at South Kensington, was founded on the principle described by Philibert Delorme, in his work entitled "Nouvelles Inventions pour bien bastir et à petits fraiz," published at Paris in 1561. In this book the writer draws attention to the method he had invented of making trusses composed of numerous pieces of wood framed together into a semicircular arched rib. Each truss was formed of two thicknesses of inch boarding sawn to the sweep, and put together in lengths of 4 feet, the lengths being so arranged as to break joint. Delorme's entire treatise is devoted to the description of the mode of constructing these trusses for roofs and floors, and he enumerates very quaintly the advantages of the invention, and the benefits to be anticipated from the adoption of the system, both in France and in other countries. It would appear from the context that Delorme employed this truss in his restoration of the Château de la Muette, at St. Germain-en-Laye, the central hall of which had a span of 10 toises (64 feet), and he states that the new roof had proved thoroughly sound and substantial. From the numerous woodcuts it would seem that the boards were pegged together, and that the ribs were placed 2 feet apart, being tied together by battens or purlins, 4 inches by 1 inch, passing through the centre of each, in mortise-holes at the junctions of the short lengths. Stout wedges, driven through the purlins on either side of the ribs, served to tie the work together. The accompanying illustration (see next page) shows the form of truss used for small spans. For larger spans, such as the roof of the Château de la Muette, Delorme designed a more complicated system of inter-ties, full details of which are given in his book.

Notwithstanding the obvious advantages of this mode of construction, in a country where large timber was becoming scarce, it does not appear that it was much practised, and the Author is unable to trace any work of importance in which it was adopted until the construction of the roof of the Halle aux Blès, at Paris, in 1783. Previous to this, arched ribs of laminated timber, on the principle invented by Colonel Emy, had been employed in France with advantage for large spans. This latter system has attracted the attention of English engineers, having been successfully adopted by Mr. L. Cubitt for the roof of King's Cross Railway Station.

Tredgold, writing in 1820, in his "Elementary Principles of Carpentry," states, in Article 171, that "to make principal rafters in a continued series of pieces abutting end to end against one another," would remedy the defects in roof-trusses arising from the shrinkage of timbers in large spans; and, in Fig. 55, he furnishes an illustration of the mode of constructing a principal of this kind. He also shows, in Fig. 57, how such a truss would be adapted to a span of 100 feet; but he indicates the parabola as the proper curve to be employed, and it is clear that he contemplated the use of much stouter timber than that proposed by Captain Fowke. The truss is shown to be composed of three thicknesses of sawn timber, each length breaking joint, bolted and tied together in the form of a parabola, with a rise of about one-eighth of its span.



Delorme's System.

Captain Fowke's truss was first employed in the construction of the drill-shed erected at South Kensington in 1858, for the First Middlesex Engineer Volunteers. This building was a marvel of cheap construction, as the total cost for enclosing 90 feet by 40 feet was only about £100. The exterior was covered with felt; the skylights being formed of oiled calico. The ribs, which were 10 feet apart, were composed of three thicknesses of ¾-inch boarding; the rafters, placed at intervals of 2 feet from centre to centre, were 3 inches by 2 inches.

Shortly afterwards Captain Fowke employed the same principle for the "temporary" entrance to the Royal Horticultural Gardens (a building still in existence), and for the machinery annexes of the Exhibition of 1862, in which latter case three parallel lines of sheds, 50 feet in width, were erected side by side.

Recently the system introduced by Captain Fowke has been used on a very extensive scale for the buildings constructed at South Kensington, under the late General Scott, for the Fisheries Exhibition, and much attention has been directed to this very simple and economical truss. As the Author believes that the system has not been illustrated, he has prepared some details of the mode of construction (see Plate 5).[1] However carefully this kind of truss may be put together, it has a tendency to spread at the springing, to counteract which it is advisable to secure the feet of the rib to a firmly-fixed plate or sill, and, in setting out the upright sides of the structure, it is as well to make the total width at the eaves (for a span of 50 feet) 6 or 7 inches less than at the springing; by this means, when the truss is fixed in position and fully loaded, the haunches will give sufficiently to bring the sides upright.

Owing to the extremely small lateral rigidity of this form of truss, it is necessary to take strict precautions in rearing it into the vertical position, after nailing it together on the floor, as otherwise it may become greatly crippled. The Author has found it advisable to lash crossed scaffold-poles at back and front, and across the springing, in order to render it stiff enough to hoist. Care must likewise be taken to connect together the several trusses with purlins and wind-braces, as fast as they are raised, as, until the various ribs are securely attached together, they have not sufficient rigidity to resist a gust of wind. A length of several hundred feet of sheds was instantaneously demolished at South Kensington, owing to the neglect of these precautions.

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[1] It will be seen that Captain Fowke used 9-inch boarding, not sawn to the sweep, and in lengths of about 6 feet; by the occasional insertion of radiating braces, combined with double planks for the vertical framing of the sides and for the principal rafters, a manifest improvement on Delorme's principle is secured.

Where internal height is not a matter of importance, it is expedient to make the arch rather less than a semicircle; and the Author has found much difficulty with structures of this kind, in which the arch was stilted several feet above the springing, as in the example given, where the stilting is 6 feet. A notable advantage of this system of construction is that the building internally assumes a decorative appearance, and readily lends itself to decoration; it is also very much cheaper than a wood, or wood-and-iron, truss of the ordinary kind.

The communication is illustrated by one drawing and one sketch, from which Plate 5 and the cut have been engraved.

HONE
rt of Bouc
1000
10000
100

Fig: 7.

BAR AT MOUTH OF RHONE IN 1873.

SECTION ALONG FAIRWAY CHANNEL.

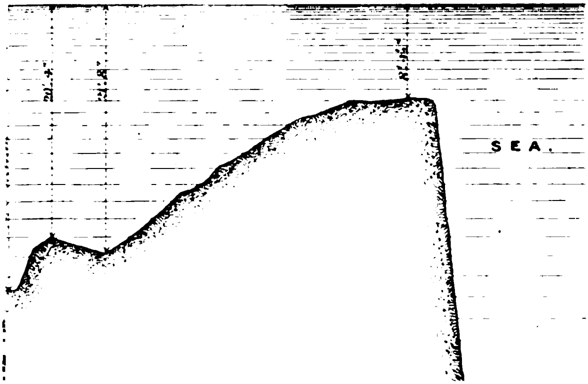
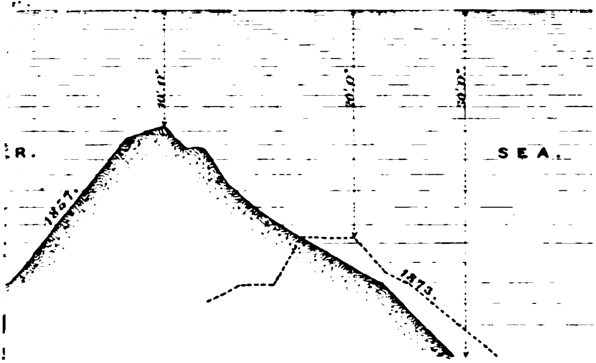


Fig: 8.

RIVER DANUBE. BAR AT SULINA MOUTH.

1857 AND 1873.

SECTION ALONG FAIRWAY CHANNEL.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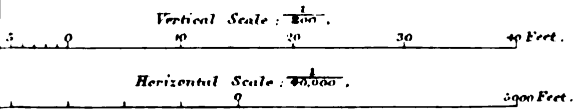
R.
SEA.
1857.
1873.

SCALES FOR SECTIONS.


Vertical Scale: 1/200.
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0
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20
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40 Feet.
Horizontal Scale: 1/10,000.
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5000 Feet.

THOS KELL & SON LITH. 40 KING ST. COVENT GARDEN.

(*Paper No. 2088.*)

"Mouth of the River Rhone."

By ADOLPHE GUÉRARD, Ingénieur en chef des Ponts et Chaussées,
Ingénieur en chef du Port de Marseille.

Translated from the French by L. F. VERNON-HARCOURT, M.A., M. Inst. C.E.

THE rivers of Great Britain have a special regimen, which presents little resemblance to the large rivers of continental Europe. It is therefore not surprising that the methods employed for the improvement of the mouths of the rivers should differ in the two localities.

The regimen of a tidal river differs completely from a tideless river, where the other conditions are the same. It appears therefore impossible that the methods adopted, or proposed, in the two cases can be compared. The regimen of the outlet depends both on the regimen of the river, and on that of the sea at the point where the fresh waters are discharged; whilst the circumstances which combine to constitute what is termed the regimen, either of the river or the sea, are so numerous, so varied, and at the same time so little susceptible of precise determination, that it appears difficult, not indeed to define, but merely to state in a general form the differences which may exist between the two cases, without being liable to errors or omissions. The Author therefore fully agrees with the opinion expressed by Mr. William Shelford, M. Inst. C.E., in his Paper "On Rivers flowing into Tideless Seas, illustrated by the River Tiber," "that every river should be separately studied."[1]

In order to indicate better the circumstances which he considers should be taken into account in the improvement of the mouths of tideless rivers, the Author proposes to follow an inverse order to that adopted in the above-mentioned Paper. He will investigate one of the most complex instances in existence, namely, the outlet of the Rhone into the Mediterranean, and see how the problem might be modified in other cases. The study of the mouth of the Rhone presents a peculiar interest. During some centuries attention has been directed to its improvement, that is, to the means of rendering it available for navigation. Two entirely different methods have been successively applied for this purpose; firstly, the construction of embankments, which the designers supposed would fix and deepen the channel over the bar; and secondly, the formation of an artificial outlet with locks, known as the St. Louis Canal.

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[1] Ante, p. 16.

DESCRIPTION.

The Rhone divides into two branches, 5 furlongs above Arles, which flow into the sea by two distinct outlets, 23½ miles apart (Plate 6, Fig. 1). The principal branch, the Great Rhone, passes by the town of Arles, and going in a south-easterly direction, after a course of about 32 miles, falls into the sea at the entrance of the Gulf of Foz, about 4 knots to the south-west of the port of Bouc. The other branch, the Little Rhone, has its mouth to the west of the Gulf of Beauduc, near the village of Saintes Maries; its length is 36 miles. The island of Camargue, situated between the two arms, like all deltas, has a triangular shape, and is a low-lying level tract of land, rising near the river, with low sandhills on the seashore and lagoons behind. It has an area of over 178,000 acres. The waters of both arms are kept in their channels, up to the neighbourhood of their outlets, by embankments, having a total length of about 95 miles; and about twenty-five years ago a long insubmersible dyke was constructed along the sea-coast, between the two mouths, which prevents the inroad of salt-water on to the island of Camargue. Consequently, the fresh and salt waters do not come on the island, except through the inlets which have been formed across the embankments, either for irrigation, or for supplying the salt marshes and fisheries; or, indeed, when a breach is made in the embankments, owing to an extraordinary flood of the Rhone, or a storm on the sea-coast.

The Rhone at Arles has a width of 500 feet at low-water level, and its greatest depth is 46 feet. Its width below is very irregular; in some places it amounts to 5 furlongs, and then the channel is obstructed with islands. At St. Louis, its width is 1,100 feet; its greatest corresponding depth is 25 feet, but at most over only a tenth of the width. Lastly, the distance between the two embankments, at the outlet into the sea, is 1,300 feet, with a corresponding maximum depth of water of 19⅔ feet. The depth varies considerably. Large embankment works have been executed, with the object of regulating the course of the river and augmenting its depth, consisting of longitudinal banks and submersible spurs, by which notable improvements have been obtained. But at certain points between Arles and the sea, it is impossible to get more than 6½ feet draught of water, because a bank of very hard puddingstone is encountered, for a great length, right across the river-bed, which the current cannot erode. At all other points, doubtless, the embanking would suffice to ensure a fairly regular channel, with a draught of 13 feet of water up to the mouth.

REGIMEN OF THE RHONE.

Discharge.—The Great Rhone alone need be considered, as no navigation exists on the other branch owing to its shallowness. The total discharge of the Rhone during the greatest floods, at the point where it divides into two branches, is estimated at 13,000 cubic yards per second. According to simultaneous observations in both of the arms, the Great Rhone receives 84 per cent., and the Little Rhone 16 per cent. of the flow.[1] Some direct gaugings taken at Arles give the discharge of the Great Rhone as 650 cubic yards at low water, and at the highest stage, during the flood of 1856, 10,200 cubic yards per second. At the low stage, the total fall from Arles to the sea is 5·86 feet; whilst during the flood of 1856, the greatest on record, the river rose at Arles 18·11 feet above the low stage, or 23·97 feet above low sea-level.[2] The river is, on the average, at or below the low stage for thirty-four days in the year; it is generally at a height of between 1⅔ foot and 5 feet; and floods exceeding 14¾ feet occur once in four years. At St. Louis, the level of the river greatly depends on the height of the sea. It is generally 1⅔ foot above low sea-level; the highest observed level, caused by a flood, rose to 6⅙ feet; and the river usually falls once a year down to 2 or 4 inches below low sea-level. The maximum surface-velocity at St. Louis is generally 1⅔ foot per second; it attains 8⅕ feet during the greatest floods.

Gaugings made at Arles have enabled the curve of the discharges of the river to be traced in terms of the height of the water measured at the gauge of that port. By means of this curve and the daily gauge readings, the total volume of water discharged into the sea by the Rhone, in the course of a year, was calculated to amount to 51,300 million cubic yards in 1869, and 46,113 million cubic yards in 1870. The Author considers that the first figure represents fairly approximately the average yearly volume.

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[1] "Mémoire sur l'amélioration des Embouchures du Rhône. Par M. Surell, Ingénieur des Ponts et Chaussées." Beaucaire, 30th May, 1847. Printed at Nimes in 1847.

[2] Low sea-level is the level adopted for the zero of the tide gauge of Fort St. Jean at Marseilles, and corresponds, within 4 inches, with the lowest sea-level observed at that port and on the sea-coast at St. Louis and Bouc.

Alluvium.—The Rhone brings down a considerable quantity of alluvial matter. In the upper part of its course it carries along mud, it brings down sand, and rolls shingle along. The shingle disappears at Sanjean, 4½ miles above Arles, and none has ever been found below. Between this point and the sea, only mud and sand are found in the water. The soil of Camargue Island consists exclusively of these materials, and no shingle is ever found there. The bed of the Rhone between Sanjean and the sea is entirely formed, except in the Arles reach, of sand more or less muddy or silty. Attempts have been very often made to estimate the volume of solid material which the Rhone discharges into the sea. These investigations, however, present very serious difficulties. The quantity of mud and sand held in suspension can indeed be estimated fairly correctly by means of direct experiments; but the difficulty consists in determining the amount of material which the river only rolls along its bed and its sides. According to experiments made forty years ago, Mr. Surell, Ingénieur des Ponts et Chaussées, who was entrusted at that time with the investigations for the improvement of the mouth, estimated the quantity of mud and sand which the Great Rhone threw annually into the sea at 22¼ million cubic yards, and the amount discharged by the Little Rhone at 5¼ millions. He calculated that out of the 22¼ million cubic yards brought down by the Great Rhone, 19⅝ millions were deposited at the mouth, and 2⅝ millions were carried out to sea.[1]

The Author has endeavoured, by means of the lines of soundings from the mouth out to the greatest depths in the sea, obtained by the marine surveyors in 1841 and in 1872, to calculate the quantity of material which has been deposited in this period of thirty-one years. He found that the silt which had accumulated in the Gulf of Foz, and round the mouth as far west as the ancient Roustan branch, amounted to 640,490,000 cubic yards, which is equivalent to 20,660,000 cubic yards annually. It was impossible to extend this calculation further west, because beyond a certain depth the chart of 1872 merely reproduces the soundings of 1841. The value obtained, of 20,660,000 cubic yards, does not appreciably differ from that which had been calculated by Mr. Surell. The Author estimates that the total volume is not far from 23,540,000 cubic yards annually; so that the average proportion of the materials carried down by the river to the volume of water is $\frac{23.540.000}{51.000.000.000} = \frac{1}{2166}$. He made daily observations at St. Louis for two years (1869 and 1870) in order to ascertain the amount of silt which is in suspension in the Rhone at a depth of 6½ feet and 50 feet from the bank. The material was collected on filters, and sent to the École des Ponts et Chaussées to be analysed. The total quantities were found to be 8,227,376 tons in 1869, and 5,669,420 tons in 1870. A cubic yard of this silt weighs about 2,700 lbs.; and the above weights correspond to 6,841,000 and 4,709,000 cubic yards respectively, in volume. These figures bear the proportions of $\frac{1}{7500}$ and $\frac{1}{9800}$ to the volumes of water, whilst their mean does not amount to a quarter of the total volume of silt brought down by the Rhone.

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[1] "Mémoire sur l'amélioration des Embouchures du Rhône. Par M. Surell."

The proportion of solid matter conveyed by the river, in different parts of the same cross-section, increases rapidly with the depth. Mr. Surell found that the proportion at the bottom, as compared with that at the surface of the water, might be as 188 to 100; but this is much less than the actual proportion, for Mr. Surell had not taken into account the materials rolled along. The Author's above-mentioned observations show that, at St. Louis, the proportion of material rolled along the bed of the river is much greater than the lighter matter held in suspension, and justify the assumption that when the river, on approaching the sea, is no longer confined by embankments, the greater part of its alluvium is rolled along its bed. This opinion is corroborated by the fact that the bed of the Rhone, in the lower part of its course, consists of fine sand; for when the river is low, immense banks appear between Arles and the sea, which are composed almost exclusively of sand. On the sea-coast also, both east and west of the mouth, nothing but fine sand, more or less silty, is found. The Rhone therefore brings immense quantities of sand into the sea. In the experiments, however, made by the Author in 1869, 1870, and 1871, for determining the proportions of silt in the water at a depth of 6½ feet, sand was obtained only nine times in eight hundred and fifty observations; and deposits of sand are found on the banks of the Rhone only after the greatest floods. Consequently the sand is mainly driven along the bottom of the river in spite of the fineness of its grains. In flood-time, the sand travels in mass; and it is not uncommon for whole banks to descend the river. Their presence is manifested at the surface by violent eddies, which appear to be produced by an obstacle travelling with the current, but at a much slower rate. These banks have been observed, by the aid of soundings, in the Piémanson and Roustan branches. Similar movable banks have been observed in the Loire, in the lower part of its course.[1]

Regimen of the Sea at the Mouth of the Rhone.

Height of the River.—The Mediterranean at Marseilles, as at Nice and at Cette, experiences very regular tides. The range of tide at Marseilles, which has only been regularly observed within the last few months, is about 10 inches. Rough weather produces much greater changes in level. In the Gulf of Foz, at the entrance to the St. Louis Canal, the sea rises 3 feet, and even 4 feet, above the low sea-level during south-easterly storms. The height of 3 feet occurs frequently, but the 4-feet level is only reached once or twice in a year. The greatest height on record of 6¼ feet, occurred during an extremely violent tempest from the

Fig. 1.

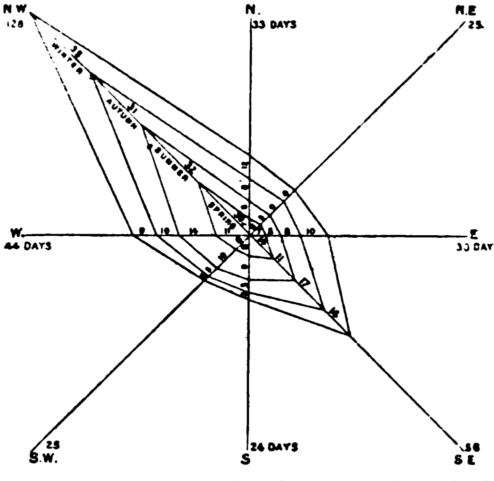

Diagram showing frequency of winds at St. Louis on the Rhone.

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[1] "Mémoire sur les sables de la Loire. Par M. Partiot, Ingénieur des Ponts et Chaussées." Annales des Ponts et Chaussées, 1871, part i., p. 233. "Note sur les rivières à fond de sable. Par M. Léchalas, Ingénieur en chef des Ponts et Chaussées." Annales des Ponts et Chaussées, 1871, part i., p. 381.

south-east, on the 25th of December, 1870; the sea rose suddenly to this height, and remained there long enough to flood all the land to the south of the canal.

Winds.—The annexed diagram (Fig. 1) indicates the average direction of the winds, as gathered from observations taken at St. Louis from 1st December, 1864, to 31st November, 1876. It indicates that the prevailing winds are the north-north-west, or mistral, and the south-east, the former blowing for one hundred and twenty-eight days, and the latter for fifty-six days, or together, on the average, for 184 days in the year. These winds are also the strongest, and raise the worst seas.

Rough Seas.—A diagram indicating the relative frequency of rough seas, like the wind diagram, is given in Fig. 2, as gathered from observations taken in the outer harbour at the outlet of the St. Louis Canal from 1st January, 1865, to 1st January, 1877.

FIG. 2.

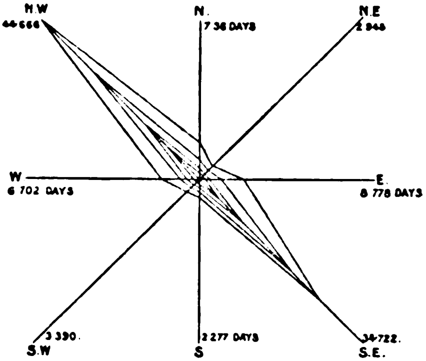

Diagram showing the relative frequency of rough seas at the outlet of the St. Louis Canal.

AVERAGE DURATION of ROUGH SEAS from 1865 to 1876.

Direction of Rough Seas.	Winter.	Autumn.	Summer.	Spring.	Total.
N.	4·171	2·300	0·306	0·583	7·360
N.E.	1·139	1·167	0·111	0·528	2·945
E.	4·000	3·167	0·528	1·083	8·778
S.E.	9·278	11·833	5·722	7·889	34·722
S.	0·806	0·444	0·083	0·944	2·277
S.W.	0·973	1·111	0·278	1·028	3·390
W.	2·750	2·067	0·802	1·083	6·702
N.W.	14·194	14·500	6·778	9·194	44·666
Total .	37·311	36·589	14·608	22·332	110·840

Rough seas are most frequent from north-west and south-east, whilst those from the south-east bring in the greatest waves at the mouth of the Rhone.

Littoral current.—A permanent littoral current from east to west exists along the shores of the delta of the Rhone, which affects the whole mass of water washing the shore down to depths of from 300 feet to 330 feet. Its existence is manifested by the peculiar form assumed by the shore of the delta in depths exceeding 100 feet (Plate 6, Fig. 1), and by the absence of all trace of deposits from the Rhone to the south-east of the cone of alluvium at the mouth, although the muddy waters of the river are very frequently carried by the wind in this direction. This littoral current has a very feeble motion, and its indications are masked by chance local currents, to whose existence the absence of precise observations, hitherto, of the littoral current is due. Its only effect is to direct the most finely-divided matter, held in suspension by the sea, in depths below the influence of the waves, namely, in depths exceeding 100 feet. It is powerless to scour any material from the coast, and it does not penetrate into the bays.

Local currents.—The fresh waters emerging from the Rhone, in calm weather, have usually a south-south-easterly course, and then turn towards the west and flow away in this direction along the coast. If the wind is blowing rather strongly from the north, they go south. With strong north-west winds, when the Rhone is in flood, the turbid waters are visible, even beyond Cape Couronne, abreast of the Port of Carry, 11 knots away from the mouth. With fresh winds from the south-west, round by south to south-east, they are driven into the Gulf of Foz.

Observations of the current issuing from the Rhone show that its velocity does not exceed 3¼ feet per second over the bar, and rapidly diminishes as it advances into the sea. These currents are only at the surface.

Currents are often observed in the Gulf of Foz, and along the coast to the west of the mouth, in calm weather. These currents, which are very slow and of very limited extent, are produced by the tides and certain accidental causes. When the sea rises, it flows into the pools bordering the coast, such as the Berre Pool (Plate 6, Fig. 1), and when it falls, the water flows back from the pools into the sea, occasioning currents which are sometimes very strong in the channels leading into the sea, and are noticeable for some distance from the coast. The canal from Arles to Bouc serves as a drain for a series of marshes ranged along its route;

the pools of the delta receive the waters of the higher lands, and some small streams flow into Berre Pool. The water from these sources discharges into the sea, causing local currents near the shore. All these currents have such a slight velocity, that, though they may influence the direction of the fresh water spread over the surface and the light silt in suspension, they are incapable of effecting the slightest erosion. Lastly, the sea itself, when agitated, produces currents.

In the open sea, a wave without wind causes no onward motion of the water; but in a wind-wave, on the contrary, the molecules of water, from the surface down to a certain depth, experience displacements in the direction of the propagation of the wave; but these displacements are effected by an alternating motion, for the molecules of water, like the floating substances, always recoil to a certain extent after their advance. This motion is increased, firstly, by the velocity of the waves, when this velocity is sufficient to make the wave break; and, secondly, by the direct action of the wind on the crests of the waves, driving forward the upper portions. This motion must not be confused with a current. When a wave, even without wind, reaches a shore having a gentle slope, its lower particles are checked in their motion, the shape of the wave is altered, and being further checked it finally breaks. There is consequently an appreciable motion of translation at the surface towards the shore, or, as the sailors say, "The ships are drawn towards the beach." This motion of translation at the surface cannot occur without an inverse motion at the bottom, which tends to increase the effect of the beach on the approaching wave. When a wave breaks upon the beach, a portion of the momentum of the water is expended in erosion and in moving about the eroded materials; the other portion is preserved by the water, and no longer acts in producing an undulatory motion, but effects displacement of the water in various directions, thus generating currents which sometimes attain considerable velocities, and are capable of producing very great results in certain cases. Some of these currents are momentary, as for instance, the recoil at the bottom; others are continuous, such as the current along the shore, which is stronger in proportion to the length of the beach on which it is formed. The force of these currents varies according to the direction in which the waves approach the shore.

WORKS FOR OVERCOMING THE OBSTRUCTIONS AT THE MOUTH OF THE RHONE.

The mouth of the Rhone is blocked by a bar of sand, nearly level with the water, through which the river forces a passage to the sea. The channel thus formed is constantly shifting, and its draught of water in certain sections seldom exceeds 6 feet. In rough weather the sea breaks heavily on the bar, and the passage is absolutely impracticable. These difficulties have always existed at all the mouths of the Rhone. It is necessary to go very far back in history to discover traces of the first attempts made to remove them.

Works of Marius.—History relates that, in the year 103 B.C., Marius having encamped near the Rhone, and being struck with the difficulties which the vessels bringing provisions experienced in approaching him, owing to the obstructions at the mouths of the river, conceived the idea of forming a large canal, into which he diverted the greater part of the stream, and whose outlet he placed at a safe and commodious part of the coast. Some learned archæologists have endeavoured to trace in these works of Marius a canal, analogous to the St. Louis Canal, having a depth of 16½ feet, and a bottom width of 328 feet, and ending in an entirely artificial port in the neighbourhood of Foz. The work of Marius was much simpler, and more rational in design. Nineteen centuries ago the Rhone was no better than at the present time. Its depth at certain points between Arles and the sea did not exceed 6½ feet, and consequently Marius had no need to form a canal 16½ feet deep at the mouth. From a comparison of the accounts of the various authors, Plutarch, Strabo, Pomponius Mela, and the elder Pliny, who dealt with the subject, it is evident that the Roman General only opened out a new bed for the river, devoting, at most, some months to these works. The river had a winding channel encumbered by sand-banks, and the outlet was obstructed. Marius opened out a shorter course into which the Rhone rushed, abandoning its ancient channel; and for some time the new river and the new outlet presented better facilities for navigation. In a few days a rudimentary canal was dug, which sufficed to induce the diversion.

The transformation in the outlet of the Rhone which occurred in 1712 affords the best idea of the works conceived and executed by the Roman General. Previous to 1712 the river did not follow its present course. At 10½ miles above its present mouth it flowed into a very winding branch, called Bras-de-Fer or Canal du Japon (Plate 6, Fig. 2), which conveyed all its waters to the sea by a route 16 miles in length, or 5½ miles longer than its present course, of which very distinct traces still remain. Along the site of the existing channel there stretched a line of saline pools, which the collectors of the royal excise on salt undertook to unsalt by admitting fresh water into these through a canal, known as the Lannes Canal, with the object of putting a stop to fraud. In 1712, the Rhone carried away the sluice which guarded the entrance to the Lannes Canal, and finding a ready-made channel leading direct to the sea, by a route only 5⅝ miles long instead of 16⅛ miles, it rushed along it; and the new channel thus formed was preferable to the old one.

In the eighteenth century the only works executed consisted of rubble-work for protecting the banks, and some groynes.

Canal from Arles to Bouc.—The canal from Arles to Bouc was constructed in 1802. This canal, however, having a depth of 6½ feet, and a width in the locks of only 26¼ feet, became inadequate directly steam navigation was established on the Rhone.

Embankment of the Mouth of the Rhone.—In 1840, the problem of improving the mouth of the Rhone was again brought forward. After some important investigations by Mr. Surell, it was decided to seek a solution of the difficulty by concentrating all the discharge of the river into a single channel by means of a series of embankments, so as to drive the whole current over the bar, in preference to the construction of a lateral canal. The state of the mouths of the Rhone in 1841 is represented on Plate 6, Fig. 3.

The works executed between 1852 and 1857 are shown on Plate 6, Fig. 6. The Piémanson, Roustan, and Eugène arms on the right bank were closed, and the secondary branches of Tartane and Pégoulier on the left bank; and the places of the banks liable to scour were protected by rubble stone. The embankments were terminated at a distance of 2,300 feet above the site occupied by the bar in 1852; but when they were finished in 1856, the bar was 1,000 feet further out, or 3,300 feet beyond their extremities. Before the execution of the works, the draught of water over the bar was usually 3½ feet; and a continuous series of observations, made during the eight months from 1st August, 1846, to 31st March, 1847, indicated a maximum of 9½ feet, and a minimum of 4⅞ feet. The depth of water over the bar appeared to increase in proportion as the embankment works advanced, though keeping within the limits previously observed. In October 1855, although all the secondary arms were closed, and the embankments executed, the bar channel had barely 6½ feet of water; but shortly after a very great flood increased the depth to 11½ feet. The channel, however, gradually silted up, and two months later, in February 1856, it had only a depth of less than 8½ feet. After the extraordinary flood of May and June 1856, there was a fresh deepening, and at the end of September the depth over the bar was 13¾ feet. This deepening, however, was merely temporary; and soon after there were the same depths as previously, and since then the depth has varied between 2⅓ and 9½ feet, averaging about 6 feet (see Table, p. 328). The failure of the embankment works having been clearly established, it was determined to fall back upon the expedient of forming a lateral canal with locks; and the works of the St. Louis Canal were decreed to be of public importance on the 9th of May, 1863.

The St. Louis Canal.—The St. Louis Canal is shown on Plate 6, Fig. 6; its arrangements are well known. Its draught of water is 19⅔ feet at low sea-level; its width is 100 feet at the bottom, and 207 feet at the surface of the water. The channel into the sea is 200 feet wide, at the bottom, from the shore out to the 4-metre (13 feet) line, and 656 feet wide from the 4-metre (13 feet) to the 6-metre (20 feet) line. The canal is separated from the Rhone by a lock having a depth of water of 24½ feet, a width of 72 feet, and an available length of 525 feet. Below the lock, at the commencement of the canal, a basin has been excavated, 30 acres in area, and with 20 feet depth of water. The works were begun in 1863, and finished in 1873.

The St. Louis Canal is a work of far greater importance, as regards navigation, than the results anticipated from the improvement of the mouth of the Rhone. The object of the embankment works was merely to open the Rhone to vessels finding a sufficient depth to get up to Arles; but this depth was restricted to 6½ feet at low-water level. The St. Louis Canal works, however, afford access to the Rhone for vessels up to 20 feet draught, and provide these vessels a harbour, opening into a sheltered bay, in which they are able with ease to load and discharge their cargoes.

The project of the St. Louis Canal was from the first very fiercely assailed by the partisans of the embankment works, as well as by those who considered that the proper expedient was to enlarge the canal from Arles to Bouc. It was urged that the canal would soon be silted up by deposits from the Rhone, both at the sea end and also at the lock. Most careful observations, carried on for ten years since 1873 to the end of 1883, enable the importance of this objection to be fully determined; they give the following average results for one year:—

(1) *Accretions from the Rhone.*

	Cubic yards.
Entrance channel to the Rhone	26,962
Lock	2,383
Basin	13,638
	42,983

(2) *Accretions from the Rhone and the Sea.*

Canal	3,983

(3) *Accretions from the Sea.*

Channel in entrance harbour	17,357
Total volume of accretions . . .	64,323

The whole surface over which these 64,323 cubic yards are spread is 125 acres, so that, assuming this deposit to be distributed uniformly over all this area, the thickness of the layer would be 3½ inches.

THEORY OF THE MOUTH OF THE RHONE.

Description of the Bar.—A plan and section of the bar of the Rhone, in July 1873, are given on Plate 6, Figs. 6 and 7. The bar, which forms the limit of the river-channel on the sea side, takes the shape of a sinuous curve, and, joining the shore at each end, extends across the whole river-channel, and, protruding into the sea, presents its concave face to the river current, as if the current was endeavouring to force it out to sea. The plan of 1873 shows the channel open to the south-east. The channel frequently shifts, and wanders through every position comprised between S. and E. ¼ N.E. On its southern side the bar assumes the form of a very narrow mound, on whose crest there are only a few inches of water at low water. To the north this mound is replaced by a wide plateau with rounded contours, approximately level with the sea, on which at some places land emerges forming islets, whose surface is but little above the ordinary sea-level; and along the edge of this plateau, to the east, the bank rises, forming a sort of shore line alongside the sea. The 2-metre (6½ feet) line inside indicates exactly the configuration of the river bed adjoining the bar channel. On the south side, the bed of the Rhone is less clearly defined, for even the inside 2-metre (6½ feet) line follows the curve of the bar. These peculiarities seem to indicate that the fresh water escapes more readily into the sea on the southern side than on the northern, and thus manifest a tendency in the bar channel to turn towards the south. The width of the bar channel in 1873 was 820 feet, at a depth of 6½ feet, and its depth in the fairway was 8⅓ feet. Looking at the longitudinal section along the fairway of the river (Plate 6, Fig. 7), it will be observed that inside the bar the depths continue fairly small for a long distance; whereas outside, the bottom dips down very rapidly. On proceeding further up the river the depths increase very gradually, attaining 20 to 23 feet at 9 furlongs above the bar. The bed of the river accordingly forms an incline rising towards the bar. On the sea side, the 10-metre (33 feet) depths are only 525 feet distant from the crest of the bar in the pass, which gives an incline of 1 in 21. To the south, as well as to the north of the pass, the incline is even steeper, reaching 1 in 7 on the south side, and 1 in 13 to the north-east. This steep slope exists all along the eastern face of the bar promontory, from south round to north-east. Beyond, it diminishes abruptly, and only the ordinary slopes of the beach of the delta are found.

Position of the Pass over the Bar.—Since 1852, the bar-channel has been very attentively watched. Some pilots, inhabiting cabins on the north-eastern shore of the delta, inspect the pass every day when the weather permits, signal its positions, sound the depths, and steer the vessels which cross it.

The great floods of the Rhone, rising over 13 feet on the Arles gauge, always open a single pass in the direction of the line of the embankments; and the channel between the ends of the embankments and the bar follows a straight course. After a flood, the pass is always deeper than at any other time, having sometimes over 11½ feet of water. After a short time, the depth diminishes, and at the same time the pass gradually shifts towards the south, and only stops at the point where a line running due east and west is a tangent to the 2-metre (6½ feet) line. The channel is then curved, with its convex side to the north-east. The pass remains in this position as long as the river at Arles does not rise higher than 6½ feet above low-water level. Floods rising over 6½ feet, and under 11½ feet, cause disturbances in the pass; they commonly open a secondary pass in an easterly direction. The two passes co-exist, and neither of them is deep; their depth of water does not exceed 5¼ feet, their instability is greater even than that of the single pass, and they oscillate to the right and left of their primitive position. This condition generally continues till a great flood comes down.

A pass is never formed in a northern direction having as much as 3¼ feet of water. The channel leading to the bar modifies its line according to the position of the pass, starting from a point about 2,300 feet from the ends of the embankments, its various positions being comprised between S. and E. $\frac{1}{4}$ N.E. Such has been the condition of the mouth up to the present time since 1852. It differs from what it was formerly when the Rhone flowed into the sea through several mouths; it will be changed again when, at a time not far distant, some secondary mouths shall have been opened.

Causes of the Formation of Bars.—Opinions differ as to the causes to which the formation of bars at the mouths of tideless rivers must be attributed. Mr. Surell has devoted a whole chapter to this question in his Paper on the improvement of the mouths of the Rhone.[1] After having reviewed the opinions expressed by Colonel Émy, who attributed bars to the *flot de fond;* by the physicist Aimé, who explained their formation as the effect of a back sea under current in the form of an eddy produced by the surface fresh-water current; and, lastly, by Élie de Beaumont, who regards bars merely as continuations of the shore lines formed exclusively by the action of the waves of the sea; and after having investigated the results at the mouths of some rivers and at the confluence of streams, Mr. Surell enunciates his opinion on the causes producing bars at the mouths of rivers as follows:—"The formation of bars depends upon a general law which is modified by a great number of causes. A bar is formed because the sea, aided by the winds and currents, tends to close the mouths of the river. It is also formed because the river, charged with matter and opening out into a channel without banks, loses its velocity, deposits its burden, and thus forms a shoal for the same reason that it forms shoals all along its course directly it spreads out in too large a channel." This explanation appears to the Author to be incomplete, as it does not account for the peculiar forms, so characteristic, which are found in all river-bars. The formation of bars seems to be a very simple phenomenon, whose causes are easily determined.

The actual bar of the Rhone is not the product of all the matters, indiscriminately, which the fresh water holds in suspension, but of the materials which the stream is rolling along the bed when it issues from the embanked channel and spreads out into the sea. The sea-water in front of the mouth of the Rhone has a very distinctly different density, 1·027, from that of fresh water, and a much greater cohesion. The fresh water does not readily intermingle with the salt water. The river-water, at the mouth of the Rhone, spreads out on the surface of the sea in a very thin layer, which sometimes extends as far as 9 or 11 miles from the bar. The layer of fresh water is so thin that the wash of a vessel suffices to bring the salt water to the surface, the salt water being readily distinguished, by its dark blue colour, from the muddy waters of the Rhone.

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[1] "Mémoire sur l'amélioration des Embouchures du Rhône," p. 48.

Some observations, made in the old Port of Marseilles at the outlet of some sewers which discharge about 1⅓ cubic yard per second, have furnished the Author with some interesting indications of what happens when a current of fresh water flows into the sea. Samples of water were drawn from different depths, and at varying distances from the outlet of the sewers. The effluent waters were very dirty, and were charged with considerable quantities of matter of all sorts. At a distance of 6½ feet, the surface-water was turbid, and measured 0° on Baumé's hydrometer; at 3¼ feet below the surface, the water was clear and measured 4° like the sea-water itself; at 3¼ feet from the bottom, and at the bottom, the water was still clear, and measured likewise 4°. At a distance of 330 feet, the surface-water was still turbid, and measured 1°; whilst the samples collected from below the surface gave the same results as before. Similar experiments repeated in the Customs Canal, where the depth does not exceed 10 feet, at the outlet of the great sewer of Breteuil Street, furnished exactly the same results. These observations clearly show that the fresh water does not mix at once with the salt water, which sorts the materials of all kinds coming out of the sewers. The heaviest solid matters settle at the outlet of the conduits, forming at this point cones of deposit; whilst the lighter materials are carried along by the fresh water, which spreads out on the surface, and are gradually deposited in proportion as the fresh water loses its velocity. The sea-water is distinctly separated, on the one hand from the solid matters forming the cone of deposit, and on the other hand from the thin layer of fresh water spread over it; and its transparency is only affected by the very limited proportion of light materials which are gradually precipitated from the fresh water.

Precisely the same phenomena occur at the mouth of a river flowing into the sea. When the fresh waters of a river reach the sea, whose water may be assumed for the moment to be motionless, they spread in a thin layer over the salt water. Directly they rise to the surface of the salt water, they are forced to abandon the materials which they were rolling along the bottom, and thus accretion takes place round the mouth whose contours, on the river side, are moulded according to the forms which the fluid mass successively assumes in passing from the river-bed to the surface of the sea. The bottom of the river-bed, starting from a certain distance above, gradually rises, not merely in the direction of the current, but also laterally; so that the surface of the accretion on the inner side has the form of an elongated basin, over the sides of which the fresh waters discharge on the surface of the sea. The drifted materials are pushed by the river against the sides of this basin, gradually mounting the slopes; and on passing the crest, they roll on to the outer slope, which is therefore naturally much steeper than the inner sides. The contour of the accretion on the seaward side would have the shape appertaining to a mound formed by alluvial deposit falling over the crest and rolling on the slope, if the waves of the sea did not exert a powerful modifying action. The accretion thus formed constitutes what is called the bar. The river-water, finding an obstacle at this bar, scours itself a passage, in the same way as it opens a channel through the banks in the river above. It advances, forming a new bar projecting in front of the preceding one, and so on. At the same time that these successive bars are forming, whilst the body of water follows a well-defined course to reach the outermost bar, the waters, which spread out on each side on losing their velocity, deposit their burden of silt, and thus a perfectly shaped channel is formed which leads to the pass over the bar. The action is quite different at the outlet of the Rhone into the Lake of Geneva. The waters of the Rhone, being charged with silt, are heavier than those of the lake, and the turbid waters are seen to slide under the clear water, and no bar is formed.

The sea, by means of its waves, contributes to the formation of a bar. When waves break on a coast capable of erosion, they throw back a portion of the materials, and tend to form, with the heaviest portions, a mound along the shore, which is termed "cordon littoral." These mounds exist in the Gulf of Foz, and all along the coast, extending from the mouth of the Rhone to Cette. When the Piémanson, Roustan, and Eugène outlets were closed, the sea immediately threw back the materials from their promontories, and formed a mound connected with the coast at the eastern side, and which, gradually growing towards the west, at length united with the other bank. A short time sufficed for the sea to bar the old mouths. The sea thus tends to form a continuous shore-line round the promontory of the outlet. If the

Rhone at any time ceased to transport alluvium, it would equally have a bar, but in this case a marine bar. This explains the reason why some rivers, which do not carry along silt, have nevertheless a bar at their outlet into the sea. Thus the Neva, whose waters are cleared of silt in Lake Ladoga, has a bar at its mouth. Many similar examples are found on the Baltic coasts, in which the bar, being of purely marine origin, is even better defined than at the mouth of the Neva. The Niemen falls into the Curische Haff, and its fresh waters only discharge into the sea through the channel of the port of Memel, the last port of Prussia on the Russian side; there is a clearly defined bar of sand at the entrance to this channel. The Frische Haff receives the waters of two branches of the Vistula and the Pregel; and the channel of the port of Pillau, which performs the same functions for the Frische Haff as that of Memel does for the Curische Haff, is obstructed by a bar of sand. Lastly, marine bars exist at the sea extremities of the outlet channels of all the pools of the south coast of France. Sea bars have not the same form as river bars, and it is impossible that it could be otherwise, since the method of their formation is essentially different. In plan, the convex curved outline is not suited to sea bars; a concave outline facing the sea is more stable. In section, the sea-bars rise higher than river-bars, as is natural. On the seaward side, the slope formed by the materials thrown back by the waves, and which the retreating water of the broken wave scours on its return to the sea, has a curved profile; the steeper incline at the top diminishes gradually till it coincides with the slope of the beach on which the continuous shore-line is formed. On the land-side, the slope is approximately straight; its incline is less than that of the outer slope.

These forms are modified at the bar channel by the waters which flow into the sea. The bar is depressed; if fresh waters flow out, the form assumed by the bar resembles a river bar; if, on the contrary, only salt waters pass through the channel, the bar is less high, and its contours are less well marked. The sea, consequently, may have a great influence on the formation of bars at the mouths of rivers.

Formation of the Rhone Bar.—The effects of the two causes which combine in its formation are easily recognized in the bar of the Rhone. The volume of sand and silt discharged by the Rhone into the sea every year amounts to 23,540,000 cubic yards. The greater part of these materials are rolled along the bed on approaching the bar. Also the volume deposited on the promontory differs little from the total volume, since the amount which remains there, in spite of the erosions by the sea, is 20,670,000 cubic yards. The promontory is developed all round the mouth.

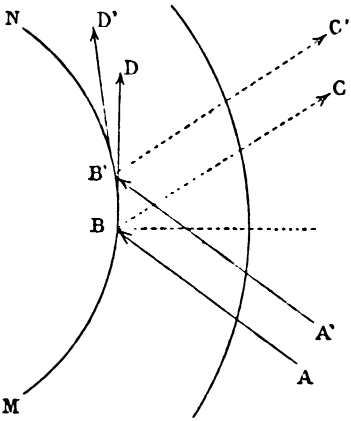
When the waters of the Rhone have crossed the bar they spread out in a thin layer, extending several miles into the sea, whose colour is more or less muddy owing to the extremely fine particles of silt held in suspension. The winds, waves, and currents have a powerful influence in directing this surface layer of fresh water. In calm weather, the river waters never flow into the Gulf of Foz, on account of the surface currents coming from the pools; they go south, and towards the west, skirting the coast of the delta. In proportion as they travel away from the mouth, they lose their velocity, and deposit gradually the silt which they held in suspension. As northerly winds blow, on the average, for one hundred and sixty-one days in the year, the layer of fresh water must go towards the south and south-east during nearly half the year. Observations show that it extends more than 8 knots into the sea. In these directions the accretions from the Rhone disappear at a distance of not more than 5 knots from the mouth. In fact, to the south and south-east of the mouth, the silt, in descending slowly from the surface to the bottom, traverses the mass of salt water which produces the littoral current from east to west, and is thus drawn along in a westerly direction. The depth of the sea is considerable in these parts, and the current suffices to make the silt travel several miles during the interval which it occupies in settling down.

The sea acts on a bar by its waves and the currents derived from them. The late Mr. Chevallier, Inspecteur Général des Ponts et Chaussées, tried to ascertain, by experiment, the force of waves breaking against an obstacle. He found that the greatest velocity which the water could have at the point where it encounters the obstacle is approximately equal to that which it would acquire in falling the height of the wave, namely, $v = \sqrt{2\,g\,h}$, where h is the height of the wave. Assuming that h varies from half a metre to 5 metres (1·64 foot to 16·40 feet), v varies from 3·13 to 9·90 metres. It follows from the above formula that waves having heights of 1·64, 3·28, 4·92, 6·56, 9·84, 13·12 and 16·40 feet, possess the same erosive power on the beach as currents having velocities of 10·26, 14·46, 17·77, 20·53, 25·15, 29·06 and 32·48 feet per second, respectively. The effects therefore of waves on the beach are infinitely greater than those of currents. Observation furnishes daily proof of this, for the slightest agitation of the sea is sufficient to set the sands in motion. The small daily movements of the waves do not modify the contours of the shores beyond depths of 6½ to 10 feet at the most; whereas the waves in storms act on the coasts of the mouths of the Rhone down to depths of 65 to 100 feet. As the action of waves in storms depends on the form of the submarine slope at the greatest depths which the waves can reach, it follows that the modifications due to the small daily motions are devoid of influence on the effects produced by storms. The form therefore of an eroded wave-beaten coast is the result, not of the little daily actions, but of the waves in storms.

The rough seas which beat upon the promontory of the mouth of the Rhone are those from the west round by south to east; the greatest storms come from the south-east. Turning to the diagram, Fig. 2 (page 9), representing the relative frequency of rough seas from the various directions, it is seen that in the direction of exposure the seas from the south-east are much the most frequent. Out of one hundred and eleven days of rough seas observed in the course of a year, there are fifty-six days from west round by south to east, and thirty-five of these are from the south-east. The permanent modifications, therefore, which are effected by the sea in the shape of the promontory of the mouth, are due to the action of the waves from the south-east. On the portion of the promontory which faces the south-east, the sea tends to push back the sands, and to drag into deep water the lighter silt which it sifts on the slope. Its undulations, however, are hindered to a certain extent by the issuing currents, and also by the presence of the fresh water at the surface, because the fresh water, having less density and cohesion than salt water, has, under similar conditions, shorter undulations and quicker oscillations. The effects of the sea-waves are thus weakened.

Considering a wave from the south-east, arriving in the direction A B (Fig. 3), at the moment when it begins to beat against the south-east side of the promontory; the line M N represents a line of equal depths near the surface, the 2-metre (6½ feet) line for example. When the wave breaks at the point B, a surface-current is produced following the tangent B D, and a bottom current in the direction B C. The waters throw back towards the surface the materials torn from the slope, and sift them; the heaviest materials remain high up, one portion remains at B, and another portion is pushed in the direction B D; the lighter particles which do not remain in suspension are drawn away in the direction B C. Such is the effect produced in a vertical slice comprised between a vertical plane A B and another plane infinitesimally near it. The same results occur at B′, in a slice infinitesimally near the last. But A′ B′ is not exactly parallel to A B, because the wave, as soon as it begins to touch the promontory, alters its course so that the direction along which it travels tends to coincide with the normal of the curves of equal depths at the points where it meets them. It follows, therefore, that the direction B′ C′ differs slightly from a parallel to B C. By degrees, as the wave breaks, it loses its momentum by reason of the reactions which it experiences; and its amplitude diminishes to such an extent that, after having traversed only a part of the face of the promontory, it dies out. The impetus of the heaviest materials at the surface of the water, in the directions comprised between the prolongation of A B and B D, diminishes gradually on travelling northwards; the surface-velocity along B D also diminishes rapidly; and, lastly, the bottom motion along B C does not extend much beyond the direction south-north, since observation shows that waves no longer break fully at points on the 2-metre ($6\frac{1}{2}$ feet) curve short of the east-west tangent.

Fig. 3.



The same effects are produced at the southern portion of the promontory, which occupies a symmetrical position to the portion just considered in relation to the south-east direction. If, therefore, no other cause intervened to divert the alluvium set in motion by the south-east waves, the highest shore line should be formed at the south-east, and develop along the eastern and southern faces of the promontory, going towards north-north-west, commencing at east, on the eastern face, and towards west-north-west, commencing at south, on the southern face; and the travel of the lightest materials along the bottom would be chiefly towards north-east and south-west. All the southern portion of the promontory, however, commencing from the east, is lapped by the littoral current. It merely forms a continuation of the south coast of the delta, which extends for a great distance from east to west, exposing a very long stretch of beach to the sea on which the waves from the south-east break with extreme violence, not having encountered the slightest obstacle in their course. The direction of this coast is most favourable to the formation of currents by the waves; and many times, during south-easterly storms, indications of drift towards the west have been observed along the coast, which seem to denote velocities of about 8 feet per second near the shore. It follows that the effect of heavy seas from the south-east against the southern face of the promontory must, on the whole, produce a powerful erosion, transporting the materials towards the west.

The effect is not the same on the northern face for the following reason. The rough seas penetrating into the Gulf of Foz find a greater depth on the eastern than the western side, and a steep shore. They therefore travel more quickly along the eastern than the western side, and wheeling round they consequently always begin to break at the eastern side on the northern beach of the gulf. The waves accordingly create a current along this beach from east to west, which would continue as far as the mouth of the Rhone, if its progress was not arrested by the jetty of the St. Louis Canal. There is, therefore, no current along the northern face of the promontory, like that along the southern face, to carry away the materials thrown up by the waves. This explains why the configuration of the promontory on the northern side is so different from that on the south, and why the accretions in the entrance harbour of the St. Louis Canal are so slight. The configuration of the promontory at the mouth of the Rhone must consequently be constantly changing. The Author has observed its alterations very attentively since 1865. Taking a series of vertical profiles, starting from the same point and approximately normal to the 2-metre (6½ feet) and 10-metre (33 feet) curves of soundings, he calculated, for the period from 1865 to 1876, the average annual displacement of the points of these curves situated on these profiles, and determined the position which the 2-metre and 10-metre curves would occupy in 1876 if this average annual displacement remained the same up to that date. The curves thus obtained are given on Plate 6, Fig. 4. The two curves have precisely the same form; they only differ in position, and in the peculiarity that the 10-metre curves are wider apart at their origin than the 2-metre curves. The 2-metre curve would attain the position of the 10-metre curve if it was moved, parallel to itself, 1,080 feet in the direction *c c′* (Plate 6, Fig. 4), approximately pointing to the south-east, and then turned from south towards north, through an angle of 21° 15′ round the point *c′*, situated on the axis of the line of the embankments and about 2,300 feet from their extremities.

The volume by which the promontory of the Rhone has increased between the 2-metre and 10-metre lines during the eleven years from 1865 to 1876 can be traced in the following manner. The upper end being represented by the surface of accretion at the depth of 2 metres, the lower end, at the 10-metre depth, will be represented by the surface bounded by the same 2-metre curve moved parallel to itself for a distance of 1,080 feet towards the south-east, being turned at the same time through an angle of 21° 15′, in a northern direction, round a vertical axis situated in the line of the axis of the embankments, 2,300 feet beyond their extremities, the origins of the surface being separated from each other. The accretions therefore at the mouth, in their constant developments, undergo a torsion from south towards the north, from the top down to depths of 10 metres, which is due to the action of the waves pushing back towards the north a portion of the materials which they set in motion, and carrying away the rest in a westerly direction. Torsion still takes place in the greatest depths, but in a contrary direction, namely from north to south, as indicated in Plate 6, Fig. 5. This is due to the littoral current which carries the lightest materials towards the west, and whose influence is felt as far as the portion of the promontory facing south-east.

Owing to these alterations of form, the channel of the Rhone over the bar must turn gradually from north towards the south, and the stable position of the pass must, consequently, be south. The axis round which the 2-metre line revolves to assume the position of the 10-metre line is exactly the point beyond which the channel changes according to the position of the pass. This point, which might be called the centre of torsion of the promontory, marks the limit at which the effect of the embankments ceases in times of average flow.

Effects of the Embankments.—The principle upon which the system of the embankments executed between 1852 and 1857 was based is laid down as follows in Mr. Surell's paper (page 57):—"The bar is a monument of equilibrium raised at the limits of two opposing forces, on the one side the river with the impetus of its current, on the other side the sea resisting the river by its inertia, or beating it back under the influence of contrary winds. Every change in one of these forces introduces at once fresh conditions of equilibrium, and gives a new form to the bar. This is the reason why the depth of water in the passes is far from being the same in all rivers. This is why on the same river, it varies according as the old mouths close up or new ones are formed. This, lastly, is the reason why it may be hoped that by modifying the arrangements of the mouth, so as to give a predominance to the action of the river, the form of the passes will be also modified so as to increase their depth, without, however, their ceasing to be shoals."

It is well known what the works were that were executed, and also that the results obtained were absolutely nothing. The pass over the bar has not gained in stability, and the depth of water has not been increased. The annexed Table shows within what limits the depth of water in the pass over the bar has varied since the commencement of the embankments down to the end of 1884:—

TABLE GIVING the DEPTHS of WATER in the CHANNEL over the BAR each YEAR, from 1852 to 1884.

Year.	Depth of Water.			Remarks.
	Greatest.	Least.	Average.	
	Feet.	Feet.	Feet.	
1852	7·37	1·57	4·59 (1)	The average depth of water has been calculated from the maxima and minima depths of the twelve months in each year. (1) Year in which the embankment works were commenced. (2) Completion of the embankment works. (3) Depth of water observed from the 25th to the 30th of September, after the great floods of May and June, the greatest floods on record.
1853	8·20	4·92	6·29	
1854	7·70	4·09	7·08	
1855	11·15	4·92	7·30	
1856	13·78 (3)	5·30	9·70	
1857	10·82	6·56	8·49 (2)	
1858	8·20	4·92	6·62	
1859	11·81	7·21	8·49	
1860	11·48	6·23	8·13	
1861	10·17	5·73	8·62	
1862	8·20	5·90	6·62	
1863	7·21	3·76	5·60	
1864	9·01	4·92	6·92	
1865	9·51	5·24	6·32	
1866	6·56	3·28	5·40	
1867	7·21	3·28	5·93	
1868	7·37	4·92	6·19	
1869	9·18	6·23	7·73	
1870	8·20	4·59	6·72	
1871	6·39	3·11	4·48	
1872	7·70	2·29	4·42	
1873	11·81	5·90	8·59	
1874	7·60	5·40	6·42	
1875	7·76	5·90	6·98	
1876	7·87	5·24	6·92	
1877	7·37	4·92	6·29	
1878	8·91	4·92	7·34	
1879	8·85	4·26	6·39	
1880	6·56	3·44	5·21	
1881	9·18	5·90	7·67	
1882	9·51	4·09	7·11	
1883	9·18	5·08	6·82	
1884	7·54	4·29	6·03	

The embankments have had a marked influence on the development of the promontory—it could not be otherwise. The Author has investigated, from a series of profiles drawn perpendicularly to the outer slope of the promontory, how this development has operated, year by year, in depths of 2 and 10 metres, from 1841 to the present time. Taking the tines as abscissas, and the displacement of the points on the 2-metre and 10-metre lines as ordinates, the curves were drawn which indicate exactly how these two lines of soundings change with the tines. These curves are not given here, since they are but of secondary interest in relation to the improvement of the mouth. It will suffice to state the facts which they manifest. The progressive motion of the 2-metre and 10-metre curves was more rapid towards the north and north-east before the construction of the embankment works than at the present time; in the direction east-north-east, the embankments have not had any influence. Within the limits of the passes, the 2-metre and 10-metre curves advanced much quicker between 1854 and 1860 than previously; but since 1860, the progression has not been more rapid than before 1852. To the south, the development of the promontory has notably slackened. The embankments have thus had the effect of diminishing the accretions on the northern side, and still more on the southern side; but, on the contrary, have increased them in their direct line, though only during a limited period extending, at the most, down to the present time.

The mean yearly displacements of the 2-metre and 10-metre curves, calculated for the period from 1865 to 1876 in the various directions, are given in the following Table:—

Direction.	2-Metre Curve.	10-Metre Curve.
	Feet.	Feet.
N.	21·45	47·86
N.E.	212·47	196·85
E.	152·65	106·63
Line of embankments	166·05	165·69 209·98
S.E.	208·37	215·16
S.	21·87	44·29

These figures are only applicable to the period of eleven years from 1865 to 1876, for the progressive motion of the promontory is far from being uniform.

The attempt made in 1852-57 is particularly instructive. The embankment works have not fixed the channel; their influence, except under exceptional circumstances, does not extend more than 2,300 feet beyond their ends; and they have not produced any deepening of the pass over the bar. The deepening observed after great floods does not result from the larger volume of water impelled over the bar, because it does not occur till some time after the cessation of the flood: it is produced because, the great floods having inordinately developed the promontory in the line of the embankments, as soon as the flood has passed away the waves remove the accidental projection, destroying it up to a point where the depth in the channel is greater than over the bar. This is the way that a temporary deepening is obtained, which the Rhone and the sea soon obliterate, the deepening being caused by the sea.

According to some gaugings taken by Mr. Surell,[1] the east branch only discharged $\frac{3}{7}$ of the total volume of the Rhone previous to the construction of the embankments. The augmentation of the volume of water impelled over the bar in the proportion of 3 to 7 has not produced any deepening. The greatest floods, during which the river throws over the bar a volume of water ten times greater than its ordinary discharge, do not increase the depth of water over the bar. Hence follows an interesting fact that the depth of water in the pass is, to a certain extent, independent of the discharge of the stream, and consequently of the absolute quantity of alluvium which it brings down. The very important conclusion to be drawn from this fact is, that absolutely no advantage would be gained by prolonging the embankments in the same direction, whether they were widened out, or made to converge. The action of the sea, therefore, can alone be reckoned upon for deepening the pass over the bar.

The embankments make the Rhone flow out in the direction exactly opposed to the course of the waves in the most prevalent storms, namely, the waves coming from the south-east. The sea accordingly tends most to raise the bar at the very point where the embankments were designed to form the pass. The sea may be said not to have any action at the north of the promontory. At the southern face, on the contrary, the materials are turned over by the sea, and carried off towards the west by the waves, by the resulting currents, and by the littoral current. It is, therefore, along the south face of the promontory that the sea would contribute to the least possible extent towards raising a bar, and would act the most energetically to disengage the pass of the materials which would tend to obstruct it. The embankments would consequently have had more chance of success if, instead of being directed towards the south-east, they had been inclined towards the south. All the results that could possibly be expected from embankments at the mouth of the Rhone would have been obtained, if, instead of closing the secondary branches so as to concentrate all the water in the east branch, the works had been limited to the construction of two embankments, suitably directed, at the mouth of the Roustan branch as near as possible to the bar, leaving all the other branches open; for it is at the point where the Roustan branch opened out, assuming it inclined towards south-south-east, that the action of the sea is the most energetic. It is very doubtful whether the desired result, namely, a fixed channel with a depth of from 11½ to 13 feet over the bar, would have been even thus obtained because the conditions are unfavourable. The river bar of the Rhone is much too high, and is constantly forming. There is, moreover, no permanent current capable of removing the least material from the beach, and it would therefore be only possible to reckon on the action of the waves for clearing the bar; but this action is not continuous, and often it only operates at very long intervals.

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[1] "Mémoire sur l'amélioration des Embouchures du Rhône. Par M. Surell," p. 26.

CONCLUSION.

The preceding investigation shows how numerous and varied are the conditions which it is necessary to take into consideration for the improvement of the mouth of a tideless river. The discharge of the river; the frequency and extent of its floods; the quantity and nature of the alluvium carried down by the current, and, on the seaward side, the winds, waves, currents, the deposits, and the density of the water, are all circumstances which deserve careful investigation on the spot before beginning any important works.

Tideless rivers which carry down silt have always a bar at their outlet into the sea. The bar is further off in proportion as the river brings down larger quantities of alluvium. The pass over the bar is more stable in proportion as the river has fewer floods, and these floods are less powerful. The depth of water in the bar-channel does not change when the volume of water in the river is increased, even to a considerable extent, and it is, therefore, to a certain amount independent of the flow of the river. The deepening of the pass over the bar is more easily attained in proportion as the materials brought down are lighter, and their volume smaller. When a river does not carry silt, like the Neva, or like the streams which flow into the sea at Memel and Pillau, the bar is formed by the sea; in such a case it is always feasible, with a suitable arrangement of embankments, to fix and deepen the pass over the bar.

The winds have only an insignificant direct influence on the bar; but the waves which they raise on the sea are susceptible of the greatest effects. The effects produced by the waves, and by the currents which they create, do not result from the little daily actions, but from the disturbances caused by storms. The waves act only intermittently, at intervals more or less distant; their action will therefore not be efficacious if the formation of the bar is continuous, as in the case of the Rhone, where the quantity of alluvium is large enough, even when the river is low, for the bar to form and develop. The effects of waves on a beach depend very much on the angle at which they attack it, and therefore the position of the mouth, with regard to the direction of the waves in the most prevalent storms, is a very important point for consideration.

The permanent littoral currents have a very great influence on the conformation of river-mouths. It is not necessary that they should possess a great velocity, for a force which acts continually, and impels an immense mass of water, is capable of producing very great effects.

Very little attention has ever been devoted to the influence that the difference in density of fresh and salt water may have on the régime of the mouths of rivers flowing into the sea. This influence, however, is considerable, even though the difference in density does not exceed 2·7 per cent. Fresh water, even when fully charged with silt, does not mingle with salt water by penetrating horizontally—a very curious circumstance, which proves that the cohesion of sea-water, owing to its viscosity, is not devoid of influence. The fresh water spreads over the surface of the sea in a thin layer, abandoning all the materials which it rolled along, and these are the materials which form the bar. If by any means the waters of the river could be prevented from expanding into a thin layer at the moment they are crossing the bar, without on that account directing all the alluvium on to the pass, a considerable deepening of the pass would doubtless be obtained. This leads the Author to the conclusion that, in certain cases, it would be possible to effect an improvement at the mouth by means of two lines of staging, or piles suitably spaced and connected together at the top by walings and ties at the ordinary water-level, these stagings being carried out beyond the bar. Special conditions, however, are necessary to enable this system to be applied, which do not exist at the mouth of the Rhone.[1]

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[1] A trial of this form of embankment was made, in 1840, by Mr. Rossi, at the mouth of the Regii Lagni, a small stream which flows into the sea to the north of Naples, and has given good results. A description of the works, and the

The height of the bar depends on the density of the sea-water. If the sea-water had the same density as the river-water, the accretions at the mouth would have an analogous form to those of the banks found up rivers, namely, banks more or less raised, but very elongated and with very gentle slopes. The waves and currents would have a greater hold on these deposits, and more power to disperse them. The continuous shore-line also would be less high. The bar is consequently less high, and more easily lowered, in proportion as the density of the sea-water is less.

On comparing the mouths of the Danube and the Rhone, a striking difference is apparent in the configuration of their accretions.[1] (Compare Plate 6, Fig. 7, with Fig. 8; and Plate 6, Fig. 6, with Minutes of Proceedings Inst. C.E., vol. xxi., Plates 7 and 8.) The Danube bar nowhere emerges. The cones of deposit at the Kilia and St. George mouths terminate in vast flats, approximately horizontal, on which there is hardly more than 1 foot or 2 feet of water, and whose external slopes are much less steep than that of the promontory of the Rhone. The Sulina mouth has only a rudimentary promontory. The Sulina bar is lower than that of the Rhone; and its inner and outer slopes are quite different to those of the Rhone bar, being approximately equal (Plate 6, Figs. 7 and 8). There is every indication that the waters of the Danube, in penetrating into the Black Sea, encounter a less resistance than the waters of the Rhone in flowing into the Mediterranean. This peculiarity is explained, to a great extent, by the low density of the waters of the Black Sea. Thus the density of the waters of the Mediterranean at the mouth of the Rhone is 1·027; whereas the density of the waters of the Black Sea, at a distance of 50 miles from the Bosphorus, is only 1·017,[2] and it diminishes on proceeding to the north-west between the mouths

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effects that they have produced, will be found in a Paper by Mr. Baumgarten, Ingénieur en chef des Ponts et Chaussées, published in the Annales des Ponts et Chaussées, 1853, part i., p. 290. Mr. Baumgarten attributes the lowering of the bar to the effect of the piles of the stagings on the waves and the littoral currents. This explanation appears to the Author to be insufficient.

[1] The Author's remarks are confined to the charts accompanying Sir Charles Hartley's first Paper on the Delta of the Danube, and to the section of the bar in 1857, previous to the execution of the piers at the Sulina mouth; but the Translator has added in a dotted line the section of the bar in 1873, after the completion of the piers, as gathered from the chart accompanying Sir Charles Hartley's second Paper (Minutes of Proceedings Inst. C.E., vol. xxxvi., plate 27). —L. F. V. H.

[2] This information was furnished by Mr. Dieulafait, Professor of the Faculty of Sciences at Marseilles.

of the Danube and the shores of the Crimea, amounting near Eupatoria to only 1·0017.[1]

The density of the waters of the Baltic Sea is reduced to 1·004 at the port of Libau in Courland, according to observations made by the Author in 1881, and it is even less in Riga Bay, in the Gulf of Finland. The banks of sand obstructing the mouths of the Neva are depressed, with very flat slopes; and the crest of the bar in the navigable branches has a length of several miles.

The mouths of the Dwina and the Windau, and the channels of Memel and Pillau, have bars; but the banks of sand which form them present the same peculiarities as those of the Neva, and solid jetties suffice to maintain passes of from 13 to 15 feet deep over the bar.

Essential differences between Tideless and Tidal River-mouths.—After the preceding analysis, little need be added to show how completely the problem of the improvement of the mouth of a river is changed, when, instead of a tideless river, like the Rhone, the Danube, or the Tiber, a river flowing into a sea subject to high tides has to be considered. Owing to the tides, large quantities of salt water enter and leave the river at regular intervals. The entrance and outflow of the salt water takes place under special conditions which require investigation. Here again the density and viscosity of the sea-water exercise a great influence, and it is a mistake not to take them into account in the consideration of river-mouths. The sea-water at the mouth of a river is distinctly separated from the fresh water; but the line of demarcation does not follow a vertical plane, across which the waters gradually commingle. The tidal water, moreover, does not act as a dam, entirely stopping the mass of fresh water, and in rising keep back the river water, only forcing it up-river at the moment when the currents reverse their course. On the contrary, the fresh water spreads over the sea; and when the tide rises, the salt water at a definite period, which could only be ascertained by experiment, penetrates into the river, introducing itself like a wedge between the bottom of the river-bed and the mass of fresh water flowing out above it, and this occurs some time before the current is reversed. The Author has observed this fact many times at the lock of the St. Louis Canal, where moreover the tides are very feeble, their rise being generally only 10 inches. The fall at the lock amounts to a few inches only when the river is low, being comparable to the range of tide which is experienced below the lock. The gates are immersed in fresh water on their upper side, and in salt water on their lower side, whose density exceeds that of the fresh water by 0·027. The total statical pressure on the lower side of the arched gates is equal to that on the upper side when the upper water-level is only 4¾ inches above the lower water-level. If, owing to the tide, the lower water-level rises slightly above this limit, the pressure below exceeds the pressure above, and the gates open of themselves to an extent varying in proportion to the difference of the pressures, and the water from the upper level rushes through the gates over the salt water. Along the bottom, at the same time, a current is generated upstream, which is rapid enough to prevent a wooden sounding-pole, which has been sufficiently weighted to sink to the bottom, from being held upright.

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[1] This information was furnished by Mr. Trichaud, director of the salt works of Saki on the Crimean coast, near Eupatoria.

At the mouth of a river when the tide rises, the salt water which penetrates into the river enters between the mass of fresh water which continues to flow down, and the bottom of the river-bed, taking up again the alluvium which the descending current had deposited. It attacks the deposits with more force in proportion as its mass is greater, and its action is exerted in a direction exactly opposed to that of the current which has brought them down; and it holds the materials more easily in suspension in proportion to its greater density. When the tide falls, the same salt water returns to the sea, always along the bottom. The erosion is more powerfully effected in proportion as the salt water, flowing along the bottom and charged with silt, is more dense than the salt water on the outside. The salt water, moreover, instead of spreading over the surface as fresh water would do, flows along the bottom and carries along with it, beyond the mouth, the materials it has eroded from the bar which tended to form.

The tides produce currents along the coast affecting large masses of water, whose energy is increased at the mouths of rivers by the filling and emptying of the estuary; and the deposits eroded from the bar are carried far away. This readily explains the absence of a bar at the mouths of rivers which bring down large quantities of alluvium, but which are exposed to high tides, and that many of these rivers, opening on to coasts traversed at times by rapid currents, do not form the slightest delta.

The regimen of the mouth of a tidal river, accordingly, differs completely from that of a tideless river. The improvement of the mouth in the former case seems as if it should be always possible; whereas in the latter case, special conditions are requisite for success which rarely exist. The method to be adopted in the latter case is quite different to that which is generally applicable in the former case.

The Paper is accompanied by numerous illustrations, from which Plate 6 and the Figs. in the text have been reduced and engraved.

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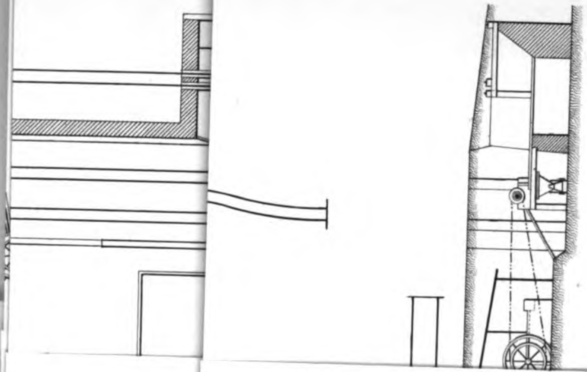
PLATE 7.



(*Paper No. 2086.*)

" Machinery for the Manufacture of Nitrate of Soda at the Ramirez Factory, Northern Chili."

By Robert Harvey, Assoc. M. Inst. C.E.

The production of nitrate of soda has, since 1869, been developed with great rapidity, and its manufacture gives employment to a vast amount of English-made machinery and capital, and many English engineers and mechanics. In 1845 nitrate of soda was produced by extracting the "caliche" or raw material from the ground, and boiling it in copper pans of native manufacture, the fuel employed being carbonized wood dug up from the Tamarugal Pampa, in the province of Tarapacá, formerly in Peru, but recently annexed by Chili, where there are in many parts indications of a sunken forest. Probably owing to the primitive method of manufacture, and the fact that nitrate of soda was not commercially known, the exportation in 1845 was only 6,000 tons. It increased by degrees up to 70,000 tons in 1859, and in 1883 the exportation of this valuable fertilizer reached 12,500,000 Spanish quintals, or 570,000 tons. Such a production would have created an excess over the demand, had not the producers formed an agreement to limit their output, so as to meet European requirements, which at present are 460,000 tons annually. This amount is produced by thirty-seven different establishments or factories, technically known as "oficinas," and by thirty distinct firms or owners, the production of English companies being 186,000 tons, or 40 per cent. of the whole. The productive capacity of the Oficina Ramirez is 140,000 quintals, or 6,360 tons monthly; but the works are now, like all the other establishments, limited to 40 per cent. of their productive capacity, or 56,000 quintals per month, giving an annual output of 30,000 tons.

The process of manufacturing nitrate of soda, and a description of the machinery of the Oficina Ramirez, which is the largest establishment of its kind in the world, form the subject of this Paper.

In September, 1882, the Author received instructions from the directors of the Liverpool Nitrate Company, Limited, who own 6 square miles of nitrate grounds in the district of Ramirez, in the province of Tarapacá, to prepare plans and estimates for the construction of an oficina capable of producing from 6,000 to 6,500 tons of nitrate of soda per month, this total being 1,000 tons more than was in the power of the largest oficina then extant. In January, 1883, the plans and specifications were laid before the directors and approved of, and the Author was instructed to order the necessary machinery (Plate 7). Six steel boilers, 30 feet long by 6 feet 6 inches, double flues, with six Galloway tubes, were constructed by Messrs. R. Daglish and Co., of St. Helen's. Twelve boiling-tanks with steel condensing tubes, ninety crystallizing-tanks, two feeding-tanks, a five-compartment washing-tank, as well as three circular tanks, 25 feet in diameter by 12 feet high, came from the works of Messrs. Preston, Fawcett, and Co. The locomotives and rolling-stock, with a length of 2½ miles of portable railway, as well as two semi-portable engines for the wells, were made by Messrs. John Fowler and Co. of Leeds, and the engines, pumps, machine-tools, &c., by Messrs. Tangye Brothers. And three crushing-machines were made by Messrs. North, Humphery, and Dickinson, of the Tarapacá Foundry, Iquique.

Having seen the contracts for plant properly placed, and having purchased the machinery required for the wells for immediate use, which was sent by steamer, the Author left for Iquique, arriving there on the 15th of May. He at once commenced making the necessary excavations for the foundations for the machinery, which came by sailing vessels on the 10th and 29th of December. The first batch of crystallizing tanks, which were shipped unriveted, reached the oficina on the 23rd of December.

Owing to the salt and other solvents contained in the soil, the greatest care had to be taken in preparing the foundations for the carrying walls, as, if only a small quantity of water should penetrate to the foundations, they would immediately become damaged, perhaps beyond repair, losing their original lines by subsidence, and thus fracturing the steam and other connections resting on them.

In making the foundations for the carrying walls, which are constructed of trimmed igneous boulders found in the locality, the ground was excavated to a depth of 12 feet, over an area of 7,500 square feet, although the walls are only 84 feet long, and 29 feet apart from outside to outside. A layer of broken boulders 2 feet deep was first deposited, and a filling of one-third Portland cement, one-third sharp sand, and one-third hydraulic lime, was run in the interstices. Next a layer of concrete, made of hard stone, of about 1-inch cubes, with one-half cement and one-half sand, was superposed 1 foot deep, and then three layers of good masonry all cemented. On this the walls were built, 12 feet high, 6 feet wide at the base, and 3 feet 6 inches at the top. This apparently excessive batter is necessary as a safeguard against the frequent earthquakes, which often cause much damage to machinery constructed on weak, straight, or high foundations. A wooden framing of Oregon pine, with the uprights and runners 1 foot square, the uprights being 5 feet 6 inches from centre to centre, was next built, on a wall 2 feet 6 inches high by 2 feet 6 inches thick, in the centre of the space between the two main walls, and parallel to them, in order to obtain a good distribution of the weight of the boiling tanks. On this framing twenty-four iron girders, 10 inches wide, 10 inches deep, and 35 feet long, were laid, and on the top of the girders the boiling tanks were bolted in sections and riveted. The inside carrying-wall is backed up by cemented masonry, 6 feet high and 4 feet wide, with an inward sloping surface, so as to catch any drainage or leakage from the ends of the tanks, from whence it flows into the passage between the two main walls by means of ten drains or conduits of 3-inch pipe built in the main wall. From the north to the south end of the floor between the walls there is a fall of 6 inches, causing all the drainage to flow to the south end, where a canal and tank are provided for its reception. Three parallel walls are built in front of the main walls, on which the washing tank, consisting of five compartments, each 24 feet by 6 feet 6 inches, rests.

The boiler, flues, and setting, are constructed on Livet's system, and give excellent results. They are built in pairs as regards flues, with a chimney 42 feet high by 5 feet in diameter, of iron, having a base of 9 feet for each pair of boilers.

The feed-water tank, fresh-water tank, top mother-liquor tank, and well-water tank, are all erected on substantial masonry built on deep concrete foundations, and rest directly on a bed of cement.

The ninety crystallizing tanks, or precipitating tanks, 16 feet by 16 feet by 3 feet deep on one side, sloping to 2 feet 9 inches on the other, in order to thoroughly drain the precipitated nitrate, are erected on a strong framework of Oregon pine, 6 inches square in section, with longitudinal, transverse, and diagonal stays, 4 inches square in cross-section. Under each crystallizing tank there are six runners of timber, 4 inches square, on which it rests, on the projecting ends of which is a plank roadway for the men in charge of the hot nitrate in solution, known as "caldo," literally boiling juice. This consists of "caliche" dissolved in boiling mother-liquor. All the crystallizing tanks with framework rest on low stone walls built on a dry rubble foundation, cement being in this case unnecessary, as leakage from mother-liquor or nitrate in solution does not dissolve the ground on which it falls.

The whole of the known nitrate deposits in the world are situated on the west coast of South America, between south latitude 19° and 27°, although there are indications of nitrate in Nevada and California.

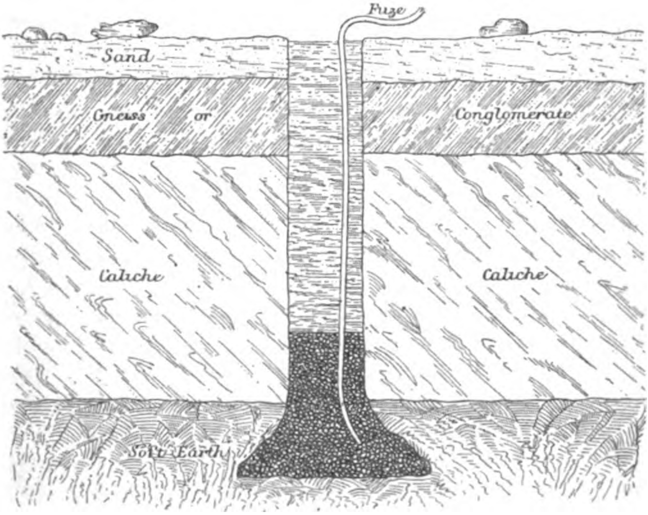
The "caliche," or raw nitrate of soda, is a mineral deposit formed, it is alleged, by the contact of decomposing animal and vegetable matter with the salts left on the retreat of the sea. This theory of its formation is supported by the frequent discovery of guano, sea-birds' eggs, fishes, feathers, birds' skeletons, shells, fossils, &c., in proximity to the caliche, and at a depth of 12 to 15 feet below the surface of the ground, and also by the presence of iodine as iodate of soda, which is peculiar to the sea.

The best deposits are found on the skirts of the Tamarugal Pampa. The caliche lays in beds of a thickness varying from 6 inches to 12 feet, beneath a covering of from 1 foot to 10 feet of conglomerate or pudding stone, or hard rock, principally porphyry, but varying also in character to foliated gneiss, greenstone, and syenite. No caliche beds are known to exist nearer than 15 miles from the sea coast, and the furthest, those in the district of Atacama, are distant about 90 miles. The Ramirez caliche beds, or raw nitrate deposits, comprise 3,270 acres, or nearly 6 square miles, and are situated on the border of the Tamarugal Pampa, 59 miles from the port of Iquique by the line of the Nitrate Railway Company, and 42 miles by direct mule road.

The caliche is plentiful and easy of extraction; its chemical analysis is, nitrate of soda, 51 per cent.; common salt, 26 per cent.; sulphate of soda, 6 per cent.; sulphate of magnesia, 3 per cent.; and insolubles, 14 per cent.

In order to provide caliche sufficient to meet the requirements of so large a system of machinery, at least two hundred and fifty mules and forty carts would be required; to avoid this expense the Author introduced the innovation of a portable railway with two locomotive engines and eighty side-tip cars, thus precluding the necessity of employing more than thirty mules and five carts for taking the caliche to the side of the line which runs out 1½ mile in the caliche quarries. This has proved a most efficient and economical mode of carriage.

The locomotives are four-wheeled coupled side-tank engines, with two-wheel trailing bogie and outside cylinders 8 inches in diameter, and having 12-feet length of stroke. The driving-wheels are wrought-iron with steel tires 2 feet 6 inches in diameter, and 4-feet wheel base; the trailing-wheels are cast-steel, 1 foot 6 inches in diameter; the weight of the engine in working order is 6 tons 15 cwt., and it carries 250 gallons of water and 5 cwt. of coal. The locomotives, as well as the cars, were designed by Mr. David Greig, M. Inst. C.E. The line has a 2-feet gauge, with steel rails and steel sleepers, known as Greig's Patent Portable Railway. The sharpest curve on the line is 60-feet radius, and the steepest gradient 3·15 in 100. The rails weigh 16 lbs. to the yard. The cars with frames and wheels weigh 5 cwt. each, and carry 1 ton 10 cwt. of caliche. The ordinary load for an engine is fifteen cars, or from 22 to 23 tons per trip.



The caliche is extracted in the following manner:—A shaft about 1 foot in diameter is sunk. Into this a boy is lowered, who forms a recess at the bottom in the shape of an inverted funnel, which is filled with a slow blasting powder (as shown in the above Fig.) made on the works, and is ignited by one ordinary fuze. This causes a dull explosion, breaking and loosening the ground around the shaft for a radius of about 10 yards. The overlying stratum of hard rock, porphyry, gneiss, &c., locally known as "costra," is removed, and the caliche extracted and split and broken by sledge hammers, steel wedges, and bars, into blocks of about 30 lbs. weight. It is then loaded into the cars and carried into the crushing machines, and there broken into cubes of about 2 inches. The three crushing machines are driven by a 25 HP. Tangye engine.

Cars stand under the mouths of the crushers to receive the broken caliche, and these when fully loaded are hauled up to the turntable by the winding-engine, and from there shoved on and the contents tipped into the boiling tank in course of being charged. The turntable is not in the centre of the six sets of rails serving the twelve boiling tanks with the side tip cars, but is on one side, and is always open to the rails which lead to the two last boiling tanks, so that in case of the winding-engine overhauling, the cars cannot be derailed. The boiling tanks are heated by a 3-inch steel spiral pipe six rows deep, 1 foot off the sides, with steam from the boilers at a pressure of 60 lbs. to the square inch. The steam enters at the top of the spiral, and leaves at the bottom of the tank by a return pipe, which leads to the return valves of the boilers, thus forming a circuit.

The boiling is effected by the well known Shanks' lixiviating system, introduced in nitrate manufacture by Mr. J. T. Humberstone, causing a continual circulation of the lighter liquid to the other boiling tanks by following the denser and heavier solution. As soon as the solution, which has now become caldo, stands at 110° by Twaddell's hydrometer, it is allowed to settle for a short time and is then drawn off into the first canal, from which it runs into the crystallizing-tanks by means of other canals. The caldo is run off at a temperature of 240° Fahrenheit.

The "ripios," or refuse, in the boiling-tanks is then washed by well water and the washings are run off into the washing tank, taking in solution nearly all the nitrate of soda which may remain in the refuse. The washings are pumped up by a centrifugal pump, and used over again in the next boiling tank. When all the washings have run off, the doors at the bottom of the boiling tank are opened, and the refuse falls into cars placed beneath, and is drawn away and dumped on the refuse heap.

After the nitrate solution has become cool, and the nitrate of soda has crystallized in the tanks, the "agua vieja," or mother liquor, is run off into a set of return canals, by which it flows into the bottom mother-liquor well, which is a round tank 25 feet in diameter and 12 feet deep, sunk level with the surface of the ground. From here it is pumped up by two of Tangye's 4-inch special pumps to the top mother-liquor tank, from whence it is run into the boiling tanks to undergo a similar process. The mother-liquor stands at 90° Twaddell.

When the nitrate in the crystallizing tanks is fairly drained, it is shovelled out on to the drying-floors, where it soon becomes perfectly dry in the tropical sun, and is put in sacks weighing about 3 cwt. each when full, and loaded on the railway cars, which are run on to the drying-floors by a siding in each floor, one hundred sacks being carried on each car. It then goes to Iquique by rail, and is exported to Europe and the United States as the well-known fertilizer and article of commerce, nitrate of soda.

The cost of the machinery, plant, and construction of these works amounted to £110,000. The whole was finished and was producing nitrate on the 23rd of May, 1884, or in the short space of six months after the arrival of the first lot of machinery. The celerity with which the machinery was placed in a state of complete efficiency is partly due to the choice of good mechanics and artizans brought out by the Author from England, and to the firms who supplied the machinery, and especially to the able assistance rendered by the manager and resident engineer, Mr. James Anderson. The disadvantages of working in a desert 60 miles from a town considerably increased the difficulties of constructing these works.

There is but one oficina on this coast with more boiler-power than Ramirez, namely that of Antofagasta, designed and constructed by Mr. J. F. Spencer, M. Inst. C.E., assisted by the late Mr. Adamson, Assoc. M. Inst. C.E.; and it is probably the finest piece of plant engineering in South America; but it has never produced more than 4,500 tons of nitrate per month, owing to the very low grade of caliche belonging to the works, the average now only containing 20 per cent. of nitrate, the remainder being salt and insolubles. The refuse thrown out from Ramirez tanks, contains only 3 per cent. of nitrate. This could be extracted by more washing, but it would cause a superfluity of weak washings and a reduction in the strength of mother-liquor, so as to need further evaporation in order to reduce the volume and raise the density. During the past six months the ratio of nitrate produced to coal consumed was as 12 to 1; or for every ton of coal burnt, no less than 12 tons of nitrate of soda were manufactured.

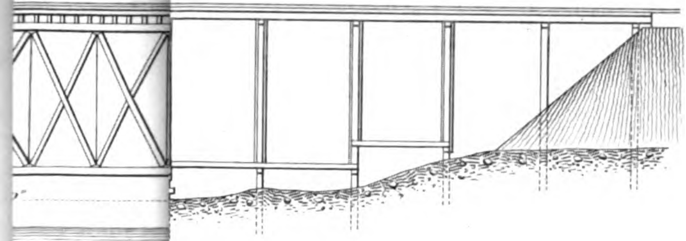
One of the most serious questions in the nitrate districts is the supply of water. The water found in wells in the Pampa collects in hard cavities by constant percolation from the melted snow on the Andes or Cordilleras. The course of this water is, however, very irregular; and there are some oficinas which have to pump the necessary water over a distance of from 4 to 5 miles. Fortunately, in Ramirez the supply of water is practically unlimited. The two wells are 82 yards deep, by 9 feet by 10 feet, timbered all the way down with 12 inches by 2 inches lining, and 6 inches by 6 inches frames at every 4 feet to bear the thrust of the lining, and to carry the guides for pump-rods. They are worked by three-throw Tangye pumps, 3 inches delivery in each, and each well can deliver 70,000 gallons in twelve hours. This water, however, is contaminated by salt and alkaline matters, which necessitates the cleaning of the boilers every two months.

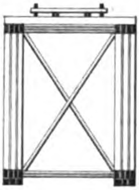
In Ramirez well-water is conveyed in pipes from the large tank to the centre of the square for workmen, for culinary and household purposes, but as this is unfit for drinking, soft water is provided by condensing the exhaust steam from the large engine and steam-pumps.

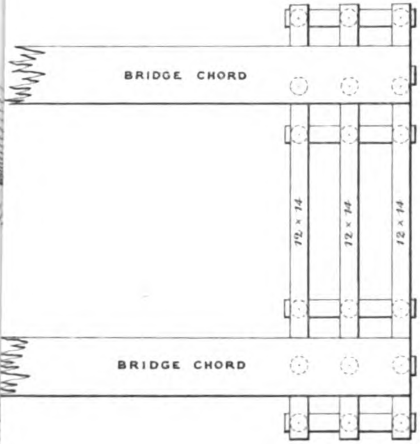
Owing to the reduced production before alluded to, only three hundred men are now employed on the works, but there is living accommodation for six hundred workmen with their families in a large "plaza," or square, and two streets. The work in this establishment is carried on both night and day, and at night the works are lighted by two 6,000 candle-power arc lights, provided by a Siemens' **A** dynamo, driven by a 4-HP. Tangye engine. There is also telephonic communication with Pozo Almonte, the nearest telegraph station to Iquique, 17 miles from Ramirez.

The Paper is accompanied by several drawings, from which Plate 7 and the figure in the text have been engraved.

PLATE. 8.



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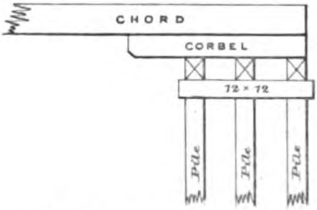
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CORBEL
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PERMANENT ABUTMENT.

Scale, 10 Feet = 1 Inch.

Feet 10 9 8 7 6 5 0 10 Feet

THOs KELL & SON, LITH. 40 KING St COVENT GARDEN

(*Paper No. 2092.*)

"Erection of a Howe Truss Bridge over the first crossing of the Columbia River, British Columbia, on the Canadian Pacific Railway."

By Charles Anthony Stoess, Assoc. M. Inst. C.E.

A description of rapid track-laying on the Canadian Pacific Railway having appeared in the Minutes of Proceedings,[1] it may be interesting to put also on record the manner and time in which the above bridge was erected.

How the ice on the Kicking Horse and Columbia Rivers would break up in the spring of 1885 being only a matter of conjecture, it was considered necessary to press the construction of the Columbia Bridge, in order to avoid accidents which might occur to the temporary structure for carrying the line over when the ice broke up.

This temporary structure consisted of pile bents, in places carrying 20-feet and 25-feet trestles. The height from rail-level to low-water was 45 feet. The bays were not all of the same length, there being longer ones where the east abutment, pier, and west abutment for the permanent bridge were to be built. In the lesser heights there were four piles to a bent, and in the greater ones six. There were two pile-drivers, each worked by two pairs of horses. All the trestle-work was of green timber, 12 inches square in section, obtained by the axe on the spot. The stringers that carried the ties and rails were all 12 inches by 15 inches; for spans of 15 feet there being five stringers, and for spans of 20 feet six stringers. At the highest places the trestles were stiffened by horizontal cross-braces just above the water-line.

The pier crib was originally designed to support masonry to be carried on piles inside the crib, but as driving these piles would have caused delay, as well as because the piles would not drive well, they were left out, and the crib filled up with stone. Eventually piles were driven outside the pier to hold the rip-rap outside together, and to strengthen the bottom. The foundation was hard gravel, fairly smooth on the surface. The pier was close built, and only settled 0·9 foot after it had taken the weight of the trusses, for which an allowance of 0·7 foot had been made.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxi. p. 383.

The trusses were of the Howe pattern, with wrought-iron tension-rods and cast-iron angle-blocks. The timber was all procured in the vicinity of the bridge, at a saw-mill erected by a contractor; it was cut, sawn, framed, and erected without any delay, Douglas fir and white pine being used for the more important parts, and spruce for those of less importance.

As an insurance against floating ice, pile clusters were driven at various points, from which it was proposed to range out booms to guide the ice and driftwood coming down the river through the bridge; but these booms were not necessary, the bridge having been completed before the ice broke up; and besides, the ice disappeared quietly and silently, melting away by degrees, the water not rising, and not a single piece of ice was seen floating down the Kicking Horse or Columbia Rivers.

The trestlework was originally designed to act as a falsework for the trusses, but as it had not been erected exactly as designed, it was decided to bolt on to the trestle-work false cross-walings to take the bottom chords, on top of which an independent false-work was erected to take the top chords in the ordinary way.

The trusses were calculated to carry a load of two 74-ton Mogul locomotives, followed by 2,000 lbs. of freight per lineal foot, the factor of safety being 8, and they are reckoned to last seven years. The deflection of the west span, with a load of one 34-ton locomotive and eight cars heavily loaded with stone, was 1·2 inch, with a permanent set of 0·2 inch; and the east span gave a similar result.

The time taken to frame and erect the crib, frame and erect the trusses, drive the piles, take down the temporary work, and stack any good material alongside the line on shore, and putting stone inside and outside the crib, was from the 7th of February to the 14th of March, 1885; the actual time for erecting the trusses, including taking up, stacking and re-laying track, was sixteen days. In criticising the time, it should be remembered that picked men were not invariably employed.

Cost of Labour.

		$	$	Cents.
295	men days framing and erecting crib to pier at	2·75	811	25
500	„ „ framing trusses . . . . . . „	2·75	1,375	00
650	„ „ erecting „ . . . . . . „	2·75	1,787	50
80	„ „ erecting approaches to trusses . „	2·75	220	00
35	„ „ taking down temporary work . „	2·75	96	25
36	„ „ lifting and stacking old material „	2·75	99	00
4	team „ „ „ „ „	6·00	24	00
162	men „ stone filling to crib and rip rap outside . . . . „	2·25	364	50
73	cars stone, $1·25 per cub. yd., 730 cub. yds. „	12·53	915	00
12	team days pile work 1,428 lineal feet . „	6·00	72	00
96	men „ „ 1,428 lineal feet . „	2·50	240	00
	Total		6,004	50

The Paper is accompanied by two sheets of drawings, from which Plate 8 has been prepared.

⁂ Mr. Stoess writes, under date the 30th of August, that "It is expected to connect the track by the end of October. The 'grading'—*i.e.* earthwork, tunnelling and rockwork—is practically completed to the second crossing of the Columbia river, a further distance of 45 miles, notwithstanding that the location has been changed since January, when the ground was covered with snow to a depth of 7 feet, and the grading was only commenced at the end of March."—Sec. Inst. C.E.

(*Students' Paper, No. 186.*)

"The Iron Bridges on the Hull, Barnsley, and West Riding Junction Railway."

By Frederick Wilfrid Scott Stokes, Stud. Inst. C.E.

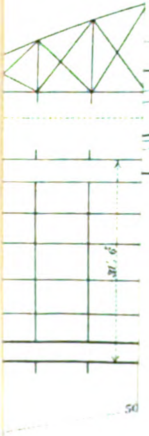
In the following Paper the leading types of the bridges on the Hull and Barnsley Railway will be dealt with. The total length of the railway under construction and now nearly completed is 67 miles.

There are in all one hundred and six bridges and culverts with iron superstructures varying in span from 10 to 248 feet. Those over the rivers Ouse and Hull are swing or opening bridges. Eleven are lattice-girder bridges; eighty-eight are plate-girder bridges; and seven are covered with built-up trough flooring. The total weight of ironwork used in their construction amounts roughly to about 6,000 tons.

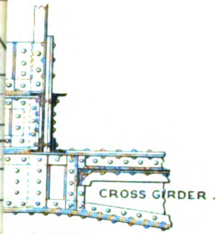
Of the lattice-girder bridges six are constructed of parallel booms or flanges and of the simple "N" truss similar to Plate 9, Fig. 9, one being a continuous-girder bridge over three spans. There are five bowstring bridges, three of which are shown in Plates 9 and 10, Figs. 14 to 41.

Of the plate-girder bridges seventy-five are of the three-girder type with trough flooring, Plate 9, Figs. 6 and 7, and five of the two-girder type with cross-girders and rail-bearers. The former class has been adopted because of the small space required for construction, the cross-sleepers being placed in the floor troughs, thus enabling the abutments, and embankments, which are very extensive, to be kept as low as possible. In no case are the rails carried by main-girders running directly under them. Durability has been carefully considered rather than cheapness in first cost, and additional weight has been put into various portions of the structures, which are more exposed to the action of the weather, in order to reduce the cost of maintenance.

The loads taken when computing the various sections required for main-girders are as follows, and are calculated from a heavy six-wheeled coupled tank engine, 30 feet 6 inches long, and weighing 46·8 tons, as shown in the annexed figure:—

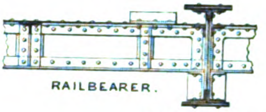


12.


CROSS GIRDER.

SS GIRDER
DER.

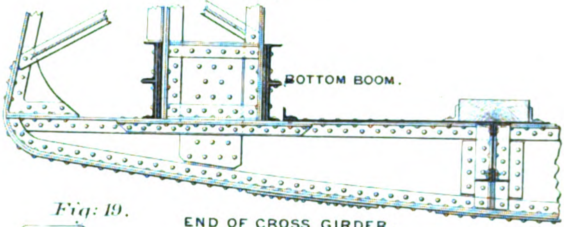
Fig: 13.



RAILBEARER.

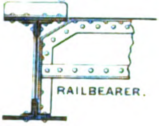
CROSS SECTION OF
CROSS GIRDER.

Fig: 17.


BOTTOM BOOM.

END OF CROSS GIRDER.

Fig: 19.


RAILBEARER.

SECTION OF
CROSS GIRDER.

Fig: 25.

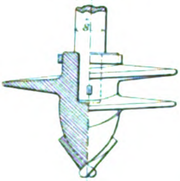
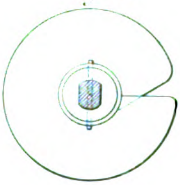


Fig: 26.



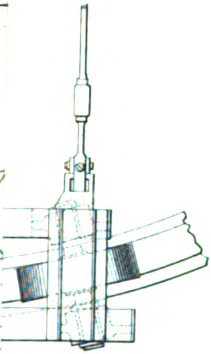


Fig: 27.

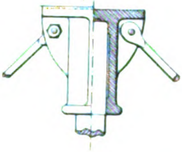
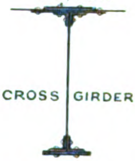


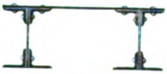
Fig: 28.



CROSS GIRDER.

DETAILS OF SCREW PILES.

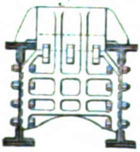
Fig: 29.



TOP BOOM.

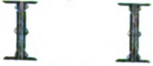
NORMAL SECTIONS.

Fig: 24.



CROSS SECTION.

Fig: 30.



BOTTOM BOOM.

nch = 1 Foot for other Figs.

10 Feet.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

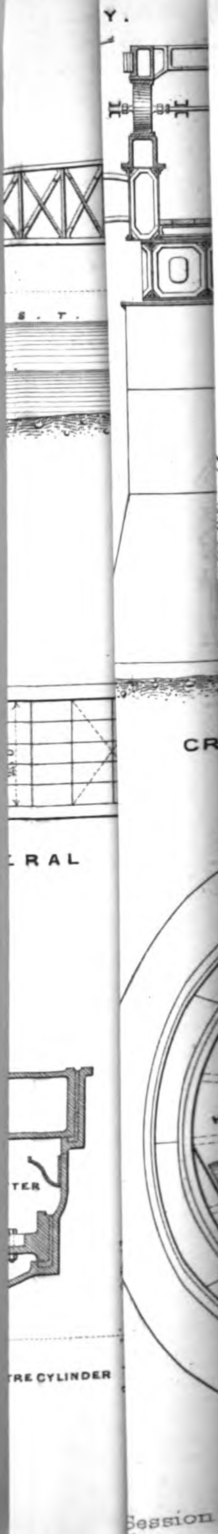
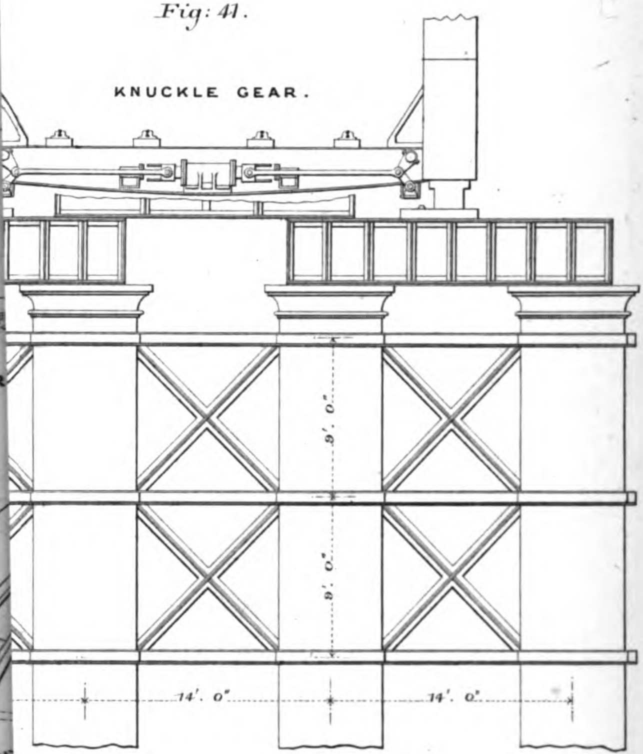
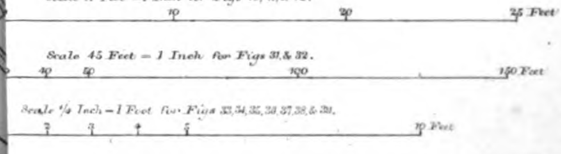

Y.
S. T.
RAL
CR
HY
TER
TRE CYLINDER
Session 1

Fig: 41.


KNUCKLE GEAR.
9'. 0"
9'. 0"
14'. 0"
14'. 0"

INTERMEDIATE PIER.

Scale 11 Feet = 1 Inch for Figs 40, 41, & 42.


10
20
25 Feet
40
50
100
150 Feet
2
3
4
5
10 Feet

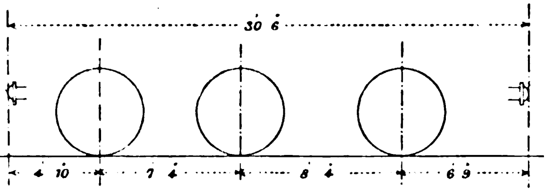
Scale 45 Feet = 1 Inch for Figs 31, & 32.

Scale ½ Inch = 1 Foot for Figs 33, 34, 35, 36, 37, 38, & 39.

THOS KELL & SON, LITH. 40 KING ST COVENT

TABLE of ROLLING LOADS.

Span of Bridge.	Rolling Load for Single Line per Lineal Foot.
Feet.	Tons.
10 to 15	3·00
16 „ 25	2·50
26 „ 40	2·00
41 „ 70	1·66
71 „ 100	1·54



Total weight 46·8 tons = 1·534 ton per lineal foot.

HEAVIEST GREAT WESTERN RAILWAY TANK ENGINE.

NOTE.—The Table is prepared for this engine.

For cross-girders 16 tons on an axle (8 tons per wheel) has been taken as the maximum local load, but further allowance has been made in providing flange-areas for the lurching of an engine, such as would bring a weight of 12 tons on one wheel, reducing that on the other to 4 tons. The same maximum weight also has been taken in calculating rail-bearer sections, assuming that the rails, which weigh 80 lbs. per yard, and the longitudinal timbers, 18 inches by 6 inches, distribute the load to a certain extent.

The strains in the girders, &c., have in nearly all cases been computed graphically.

With these general remarks the Author will now proceed to a description of a few examples.

The character of bridge-flooring adopted for the smaller bridges is shown in Plate 9, Figs. 1 to 7. It is difficult to make this form of built-up trough decking quite watertight, unless it is covered with some kind of asphalt; but in cases where it has been used for crossing streets in Hull it has been made absolutely so, by the use of Lockwood's covering, consisting of alternate layers of brattice cloth and asphalt. Before adopting this flooring, it was thought advisable to test its strength and continuity. Accordingly five troughs were riveted together and supported on timber bearers 12 feet apart from centre to centre; everything was arranged to reproduce as much as possible the strains in actual practice, and a load of 66¼ tons was applied gradually in the troughs between A and B, and D and E. The following deflections were taken at the centre of the top of each trough:—

DEFLECTIONS at the CENTRES of the TROUGHS.

Load.	A.	B.	C.	D.	E.
Tons.	Inch.	Inch.	Inch.	Inch.	Inch.
41½	$\frac{1}{16}$	$\frac{1}{16}$ full	..	$\frac{1}{16}$ full	$\frac{1}{16}$
51	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{5}{32}$
60	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{1}{8}$	$\frac{5}{16}$ full	$\frac{7}{32}$
66¼	¼	$\frac{3}{8}$ bare	$\frac{3}{16}$	$\frac{3}{8}$	¼

This, though by no means a severe test, showed very fair continuity, and that the trough "C" considerably helped its neighbours to carry the load.

Plate 9, Figs. 5 to 8, represent the girders and flooring for a bridge of 50 feet clear span over the Beverley Road in Hull. The bridge is of the three-girder type. This arrangement of girders is economical, both in ironwork and abutments, and is permissible so long as the girders do not stand more than 3 feet above rail-level, which is the maximum height usually allowed by the Board of Trade. The construction gauge is shown in dotted lines in the cross-section of the bridge, from which the economy in width is apparent. The side girders are spaced 25 feet apart over all, and the centre girder is set 1 inch low, so that the flooring may be drained through ¾-inch holes into two wrought-iron half-round gutters. The rivets throughout the girders are 4 inches pitch except in the web covers and in the main angle-irons; where those which pass through the web are reduced in the centre girder by stages from 4 inches near the centre to 2½ inches over the abutments.

The practice of reducing the pitch is not in general use; but on reflection, its propriety is obvious, as in the case of an ordinary plate-girder, carrying a uniformly-distributed load, the maximum strain in the flanges occurs at the centre, being reduced to nil over the abutments, following the ordinates of a parabola if graphically represented, Fig. 4, Plate 9. For example, suppose a strain of 100 tons at the centre in each flange, compression in the top, and tension in the bottom, and neither tension nor compression at the abutment ends, it follows that each 100 tons must have passed out from its flange, and neutralized the other; the only way possible being through the web. It will be observed that the rate of diminution of strain in the flanges increases more rapidly as the abutment is reached, and it is to meet this increasing strain on the connection between flanges and web, that the rivets through the web and angle-irons are reduced in pitch. As, however, there are two rivets through the flange to every one rivet through the web, it is not necessary to alter the pitch of the flange-rivets until it becomes more than double that of the web-rivets.

The necessary web-rivet pitch can be determined by observing the strain passed out of the flange in any given length of girder, as indicated in Fig. 4. It will be observed that the shallower the proportion of girder, the greater will be the strain to provide for. On this bridge ornamental cast-iron facia girders, which conceal those carrying the railway, are provided. A general idea of their appearance can be gathered from Fig. 8.

Before proceeding to describe the lattice-girder bridge, Plate 9, Figs. 9, 10, 11, the Author would draw attention to the considerations which should govern the general form of lattice to be adopted for main-girders, with cross-girder construction. The duty of the main-girders is to carry the load borne by the flooring of the bridge. Upon reflection it will be seen that there exists an economical distance at which cross-girders should be placed, so that the maximum weight transmitted by the rail-bearer to the cross-girder will be nearly that of a pair of drivers directly over the cross-girder. This distance is generally about 8 or 10 feet. In a close multiple system of bracing a very irregular amount of load finds its way into each system, there not being a cross-girder at each apex to transmit load. Further, the areas necessarily provided, near the centre, in the diagonals are greatly in excess of those theoretically required.

Another objection to the multiple system is, that from want of great nicety in manufacture some members cannot take the strains allotted to them in theory by the designer, and consequently a great strain is brought to bear on some, while others carry absolutely nothing.

The Author is convinced, from personal observation, that when lattice-girders are loaded they become appreciably shallower, owing to the compression of metal in the struts; the elongation in the ties yielding the deflection of the girder. This is not in accordance with the usual calculations for girders of the Charing Cross bridge type, as the verticals are thus brought into compression.

Since it is more difficult to arrange small sections in wrought iron as suitably for resisting compression as tension, those members which have to resist compression should be designed so as to receive a minimum amount of pressure and at the same time be as short as possible.

The above process of reasoning leads to the simple "N" truss, as satisfying all the above requirements, and this truss has been adopted by the Engineer of the Hull and Barnsley Railway.

Plate 9, Figs. 9 to 13, show a single system lattice-girder bridge, carrying a double line of railway over the Knottingley and Goole canal. The main-girders are 122 feet 8 inches between the centres of the bearings, 25 feet 3 inches apart in the clear, and 12 feet deep between the centres of the booms. The top boom is 2 feet 9 inches wide, and 1 foot 3 inches deep. The section is made up of four vertical plates in pairs, and eight angle-irons, arranged as in Fig. 12. A plate 2 feet 9 inches wide connects the two flitches together. The top boom is carried down at each end over the supports forming the ends of the girder. The bottom boom is similar to the top, except that there is no horizontal plate. This form of boom is designed especially with the object of placing the metal symmetrically about the lines of force, so as to bring a uniform strain over the whole of the section, and thus avoid any cross- or bending-strains. The main-girders are built to a camber of 2 inches. The cross-girders are attached to the bottom of the verticals by means of a tongue-plate, which passes up between the two flitches of the bottom boom, being riveted to them and the verticals. This arrangement applies the load carried by the cross-girders evenly and centrally to the main-girders, which is very desirable, and prevents the inner flitch carrying an under proportion of load. The rivets are also all in double shear in the connection, which is preferable to the method sometimes adopted, of simply hanging the cross-girders by the rivet-heads on to the main-girder. The cross-girders and verticals are spaced 8 feet apart. The verticals are composed of four angle-irons and distance plates. The diagonals are flat bars riveted to gusset-plates, projecting from between each pair of flitch-plates of the booms.

Special attention has been directed to the placing of the rivets connecting the various bars and plates together, so as to minimize the loss of section due to rivet-holes, as indicated in Plate 9, Fig. 11. The rivets in the boom-joints are all spaced so as to balance around the lines of force which act upon them, thus giving the theoretical advantages of pin-connections.

The main-girders are carried at the fixed end by a cast-iron rocker frame, having a 5-inch turned rocker pin 2 feet 9 inches long. The expansion end of the girders rests on five turned rollers 4 inches in diameter and 2 feet 9 inches long. The cross-girders are 2 feet deep at the centre, and 1 foot 3 inches at the ends. The flanges are 12 inches wide. The rail-bearers and flooring are sunk 5 inches below the top of the cross-girders, so as to minimize the space required for construction. By this means the tops of the sleepers are brought level with those of the cross-girders.

Plate 9, Figs. 14 to 19, illustrate a bowstring girder bridge over the North-Eastern Railway at Hull, carrying a double line of rails. The span of the girders is 140 feet; these are parabolic, 18 feet at their greatest depth between the centres of the booms. The verticals are 8 feet 8 inches apart. The diagonal bracing, except the centre bay which is of flat bars, is formed of channel-irons. The booms consist of four channel-irons and four plates; and are stiffened between the verticals by diaphragms (Fig. 16).

The cross-girders are attached underneath the bottom boom by two plates connecting the web of the cross-girder with the diaphragm plate at the bottom of each vertical. The top angle-irons of the cross-girders (Fig. 17) are stopped at this plate to allow them to clip the web, and a cover angle-iron is riveted across the gap, the angle-irons and the plates being each ½ inch thick, thus preserving the effective continuity of the cross-girder angle-irons. The ends of six cross-girders on each side of the bridge are prolonged, and carry raking struts, formed of tee-irons braced with small tee-irons. The main-girders are further stiffened by overhead bracing, which, owing to the skew of the abutments, is rather difficult to arrange.

The main girders have a camber of 2¼ inches. It is, however, in the Author's opinion, open to question whether it be correct to give a camber to bowstring-girders beyond a very small amount, as, the bottom boom being generally in uniform tension throughout its entire length, the upward curvature produces a slightly additional strain in the verticals and top boom in its effort to attain a straight line.

This bridge was built without having been previously erected at the manufacturer's works, and came together very satisfactorily and without any difficulty, the only awkward portion of the operation being putting in the rivets in the booms which connect the sides of the channel-irons together. A similar bridge made by a different firm, however, gave some little trouble, owing to the different system adopted in its manufacture. These were the only two bridges built without having been previously completely put together at the works, and in the Author's opinion, although perhaps cheaper for the manufacturer, it is somewhat risky from the engineer's point of view.

HULL BRIDGE.

Hull bridge, Plate 9, Figs. 22 to 30, is a swing bridge, which carries the railway across the river Hull, having two spans of 50-feet clear waterway. When open for railway traffic, the main-girders are supported on the two shore abutments only, but when swinging they are lowered bodily about 4 inches, so as to rest upon a central pier, composed of twelve wrought-iron piles 8 inches in diameter, fitted with cast-iron screws 3 feet 9 inches in diameter, pitched in a circle 33 feet in diameter round a central cylinder. The bridge is worked by hydraulic power, and can be swung open in either direction, but will not turn entirely round.

The main-girders, which are of the bowstring type (Fig. 20), are 148 feet 6 inches span, 25 feet apart in the clear, and 20 feet deep at the centre, the verticals being 8 feet 3 inches apart. The diagonals, which are flat bars, are riveted to gusset-plates, which project from between the main angle-irons, the flitch-plates being stopped so as to admit them. The two adjacent flitch-plates and gussets are connected by an inside and outside cover-plate. The verticals are formed of four angle-irons, riveted at the centre to web-plates, and towards the ends to plate distance pieces. The girders are stiffened by raking struts, and are further connected by head-stays and overhead bracing at the five verticals near the centre. The normal cross-girders are 3 feet deep at the centre, for the sake of great stiffness, curving up under the main-girders to 1 foot 3 inches deep. They are attached to the bottom booms by tongue-plates passing up into the bottom of the verticals.

When swinging, the main-girders rest upon four wrought-iron bogie-frames (Figs. 22, 23, and 24), each provided with two cast-steel coned wheels, 2 feet 9 inches in diameter, and 8 inches broad. The wheels of the bogie-frames are 8 feet 3 inches apart, so that the maximum weight passing down each pile will only be half that carried by one bogie, which would be close upon 45 tons in case of failure of the centre press, and 20 tons in the ordinary working of the bridge. There are also two smaller castors which serve to steady the bridge, but take no weight. The rollers and castors travel on a bevelled cast-iron roller-path, bolted to an annular girder 3 feet deep, which rests on the pile caps.

Twelve radial girders connect the pile-caps with the centre cylinder, and form a flooring, on which is laid decking carrying the hydraulic turning gear. The wrought-iron piles are braced by 2-inch bar cross-bracing in two tiers, having horizontal rings, and also radial arms to the centre cylinder. The screw-piles, which are 3 feet 9 inches in diameter, are sunk into the hard boulder clay which underlies the bed of the river at a depth of about 12 feet. Each pile, after being screwed down, was tested with a load of 60 tons, applied for seven days, and the average settlement, which was very uniform, slightly exceeded 1 inch.

The centre cylinder is sunk into the boulder clay, and is filled with cement concrete. It is lined with tarred felt to allow of the concrete swelling during the process of setting. The cylinder was tested with 281 tons applied for fourteen days, when the total settlement was $1\frac{5}{8}$ inch.

The levers for operating the bridge are situated in the signal cabin at the top of the accumulator house, which forms part of the eastern abutment, and which also contains the signal levers and usual appliances for controlling the railway traffic. In an adjoining arch is placed an 8 HP. Otto gas-engine, which works the hydraulic pumps to charge the accumulator. The accumulator is 14 inches in diameter, and has a lift of 14 feet. It is weighted to produce a pressure of 860 lbs. per square inch.

Four hydraulic presses for lifting the bridge are arranged on the abutments, having plungers 1 foot 4 inches in diameter, 6 inches length of stroke; and there is one press on the centre cylinder $26\frac{3}{8}$ inches in diameter, the top of the plunger being securely bolted to the under side of the centre box-girder, serving as a pivot, round which the bridge turns. These five presses are sufficiently powerful to raise the whole of the swinging span, which weighs about 357 tons, off the abutments.

The ends of the girders rest on cast-iron horseshoe-shaped blocks, embracing the end press-plungers on three sides. These blocks are capable of being moved inwards towards the centre of the bridge by a system of rods and wire ropes, worked by two small hydraulic cylinders on the east abutment; and they are arranged to act against either end of a lever pivoted at the centre, on the bridge, to which the rope gear is connected. There is a spring-catch lock-bolt on the east abutment.

The turning-power is placed in the centre pier, and consists of two horizontal single-acting cylinders of the usual Armstrong type, such as are seen on cranes, &c., having plungers 15 inches in diameter, and 6 feet length of stroke, fitted with sheaves and chains, with four-fold multiplying gear. The chains pass round, and are fixed to, a wrought-iron drum 14 feet in diameter. Hand force-pumps are also provided on each abutment, and the pipes are arranged so that the bridge may be worked in case the hydraulic communication across the river should be interrupted, or the main pumps break down.

All the water passes back into a receiving tank. A mixture of 1 part of glycerine to 4 parts of water is used to prevent the pipes, &c., bursting during frost. This solution will not freeze at a temperature above 15° Fahrenheit.

The working of the bridge shortly is as follows :—

1. Pressure is admitted to the centre and end presses, and the bridge rises off the bearing blocks.

2. Pressure is let into one abutment cylinder, and the resting blocks are withdrawn by the rope gear.

3. The end presses are opened to the exhaust, and the bridge sinks on to the centre pier bogies.

4. The spring-catch is withdrawn, and the bridge is then free to swing.

5. Pressure is admitted for turning the cylinder, and the bridge swings open as desired.

The bridge is closed by reversing the above operations. The difference in camber in the main-girders when the bridge is hanging free, and when resting on the abutments, is 2 inches.

The railway signals are interlocked with the hydraulic levers, which are also interlocked, so that it is not possible to work the bridge improperly. A system of detector bolts is also provided, which renders it impossible to lower the bridge unless all the resting blocks are in their correct positions; and further, electric contact is automatically broken by the first movement for opening the bridge, to give notice to the adjoining cabins that the bridge is about to be swung.

The erection of the ironwork was carried on upon a temporary staging formed of piles driven into the bed of the river. The girders were erected with a reverse camber of $\frac{3}{4}$ inch. When the blocks were slacked, and the bearing came on to the centre pier, the average deflection at each end was $\frac{3}{4}$ inch. The bridge is protected from damage when open by a permanent timber staging.

The piles were screwed down by a worm-wheel gear secured to staging. The pile shaft passing through the centre of the wheel, provided with a long key, fitted a continuous key-way cut in the pile. The centre cylinder was bolted together in lengths and calked on the staging, and then lowered to the bed of the river, when fresh rings were added as the cylinder sank. The core was removed by navvies, the cylinder being kept dry.

The peculiar construction of this bridge, which is similar to a fixed bridge when in position for the passage of trains, with only a light braced central pier to carry it when swinging, is due to the onerous requirements of those interested in the navigation and drainage of the river.

OUSE BRIDGE.

This bridge (Plate 10, Figs. 31 to 42), in point of size, is the most important work of the line. It is composed of two shore spans of 77 feet 6 inches each, reaching from the abutments to the intermediate piers, of four cylinders 6 feet in diameter, with 10-feet bottom lengths, and a swinging span of 248 feet, supported on a centre pier of eight 6-feet cylinders, with 10-feet bottom lengths, giving two spans of 100-feet clear waterway on each side.

The centre span, which is turned by hydraulic power, is protected from injury, when open to the river, by a timber staging, which also carries the hydraulic engines for pumping the water used for turning the bridge. The girders rest always on a "live ring" over the centre pier, the ends being supported when open for traffic on resting-blocks on the intermediate piers.

The main-girders of the side spans are 11 feet 6 inches deep, and are somewhat of the bowstring form, the ends being filled in with a plate-screen to meet the views of the Board of Trade. The girders are 25 feet apart in the clear. The verticals are 8 feet apart, and composed of four angle-irons and distance-plates. There is a double system of bar diagonal bracing. The cross-girders are 8 feet apart, and are riveted through the inner flitch-plate to the bottom of the verticals. They are 2 feet 6 inches deep at the centre, and 1 foot 9 inches at the ends. The flooring is $\frac{3}{8}$ inch thick, curved at the end to the radius of the swinging span, and riveted to the rail-bearers and cross-girders. The main-girders bear on rockers and cast-iron frames, on the abutment, and on the box-girders of the intermediate pier.

The intermediate pier is formed of four cast-iron cylinders, 14 feet apart from centre to centre, sunk 3 feet into the clay, which is about 14 feet below the bed of the river. The number of cylinders was determined by the area necessary to give a safe pressure on the clay, which was considered to be 4 tons per square foot.

The cylinder-tops are finished with an ornamental casting. The cylinders are filled with cement concrete, and are lined with felt. Brick rings are introduced at the joints, so arranged that in case of settlement or expansion of the concrete the weight of the superstructure cannot be brought to bear upon the castings, which are intended merely to act as a skin.

A double tier of wrought-iron diagonal bracing, 9 feet deep (Fig. 41), is placed between the cylinders, and securely connected to them by a horizontal channel-iron frame, bolted to the castings. This bracing is intended to take the shocks produced by the closing of the bridge, and to prevent oscillation from passing trains. A box-girder rests on the top of each pair of cylinders. The box-girders carry the ends of the shore and swinging spans, and are connected together by a saddle-girder, on which the end rail-bearers of the shore span rest.

Swinging Span.—The main-girders of the swinging span are also of the bowstring form, screened at the ends similarly to the shore spans.

The booms are 19 feet 3 inches deep at the centre, and 25 feet apart in the clear. The top boom is 3 feet 4 inches wide, and is composed of six angle-irons and four plates 1 foot 9 inches deep at the centre, reduced gradually to 1 foot 6 inches at the ends, placed in pairs 1½ inch apart (Figs. 34 and 39). A weather-plate runs along the top of the boom. The bottom boom is of similar section, being 1 foot 9 inches deep throughout. Diaphragms are riveted between each vertical in the top and bottom booms. The greatest strains in the booms occur towards the centre, when the bridge is swinging.

The verticals are 8 feet 8 inches apart, except the three centre bays, which are 10 feet 8 inches, and the adjoining bay, which is 9 feet 8 inches. They are composed of four angle-irons, framed round between the boom-plates, and stiffened by distance-plates. The four centre verticals are built up double, with raking struts from the underside of the top boom to projecting brackets riveted to the lower boom. There are also headstays and diagonal bracing, the two centre headstays also carrying the platform on which is erected the valve-house. A double system of the diagonal bracing is formed of flat bars. These are attached to the booms by gusset-plates riveted between each pair of vertical plates, the rivets in the joints and covers being arranged symmetrically, and placed so as to occasion the least destruction of area from rivet-holes. A sample joint is shown (Fig. 38), from which the general arrangement can readily be seen.

The normal cross-girders are similar to those for the side spans, being riveted to the lower boom-plates, and further attached to the verticals by triangular brackets (Fig. 39). The second cross-girder from the centre, on each side, is of box-girder form. These girders distribute part of the weight of the main-girders and superstructure on to the circular roller-path below. The end cross-girders are also box-girders, and contain hydraulic gear for springing the extremities of the bridge, so that the resting-blocks may be moved (Fig. 41).

Great care has been taken that the centre portion of the bridge should possess great rigidity, by distributing the weight equally over the whole surface of the upper roller-path, so that each roller may receive its due share of the weight. A circular wrought-iron distributing girder, Fig. 33, acts as an equalizer or distributor of the pressure produced by the main and cross-girders on to the cast-iron upper roller-path. On the outer face of the roller-path is bolted a toothed rack, into which gear the pinions of the driving machinery. The upper roller-path is bolted together in segments, and has twelve radial arms connecting them to a boss at the centre, which turns round the top of the centre cylinder. To the underside of the cast-iron roller-path is bolted a cast-steel bevelled face, 1 foot 4 inches wide and 2 inches thick, turned to accurately agree with the coning of the rollers.

The rollers forming the live ring are twenty-four in number; they are 2 feet 9 inches in diameter at the centre, and 1 foot 2 inches wide, being formed of cast-iron centres, hooped with coned steel tires, 2 inches thick. The centres are fitted with phosphor-bronze bushes, bored to receive the ends of the radial spokes, which maintain the rollers in their correct positions on the roller-paths. These spokes are fitted with adjustment couplings, having right- and left-handed screws and lock-nuts. The rollers are maintained in their proper relative positions by an outer and inner ring formed of angle-irons. The inner ends of the radial spokes are attached to a boss, which also turns round the top casting of the centre cylinder (Fig. 33). The lower roller-path is of cast iron, fitted with a similar cast-steel face. It is bolted to the top flange of an annular-girder, to which is fixed a wrought-iron casing, so arranged as to protect the live ring and gear from the weather. The bottom flange of the annular-girder supports twenty-four cast-iron girders, on which is bolted oak decking, carrying the hydraulic engines and gear for turning the bridge. The annular-girder rests on a rectangular box-girder, having corner brackets to connect the whole rigidly together. The box-girder is supported by eight cast-iron cylinders filled with concrete, 6 feet in diameter, with 10-feet bottom lengths, sunk at each corner, and at the centre of each side of the box-girder. These cylinders are similar to those forming the intermediate piers.

As the clay proved too elastic to be relied on for the support of the movable part of the bridge, the engineer determined to sink through it to the sand overlying the New Red Sandstone, which forms a rigid foundation, at a depth of about 20 feet.

The centre cylinder forms, so to speak, a peg, round which the bridge and live ring turn; it does not support the bridge, but contains the hydraulic accumulator (Fig. 40). A cast-iron top piece is bolted to the upper length, provided with phosphor-bronze bushes, for the reception of the centre bosses, of the radial arms and radial spokes of the rollers. Ladders are provided, with trap-doors for entering the engine-room through the bridge flooring, for reaching the valve-house, and also for descending on to the staging.

Hydraulic Machinery.—The ends of the swinging span, when open for railway traffic, bear upon four cast-iron resting-blocks, supported on the box-girders of the intermediate piers. When it is intended to open the bridge, the ends are raised by means of "knuckle gear" contained in the end cross-girders (Fig. 41), the girders springing up slightly, so that the blocks can be withdrawn by small direct-acting hydraulic cylinders, placed one under each end of the bridge. Each knuckle gear is calculated to lift 65 tons.

Spring-catches, which shoot into the ends of the side-span girders, are fitted at diagonal corners for stopping the bridge in position after swinging. They are made to fit the striking-plates with very little play, so that if the bridge is closed too quickly the bolts will not enter, but allow the girders to swing past, and thus prevent serious jar to the structure.

The turning engines and fittings are in duplicate in the engine-room, within the centre pier; they are of the oscillating, three-cylinder, single-acting type, and have plungers $3\frac{7}{8}$ inches in diameter, with 14 inches length of stroke. The crank-shaft carries a toothed wheel, connected through gearing with the pinion which works into the rack, fixed to the upper roller-path. Each engine is amply powerful to turn the bridge singly, and makes one hundred and twenty-seven revolutions to every complete turn of the bridge.

In the valve-house erected on the top of the main-girders are placed the levers, &c., for working the bridge, and also the levers for working the railway-signals, interlocked in such a manner that it is impossible for the bridge-man to operate the bridge until he has put all the signals to danger. The usual telegraphic instruments are also provided.

The first movement for opening the bridge breaks electric contact with the shore, thus automatically giving warning (if the bridge-man has neglected to do so) to the adjacent section that the line is blocked. An ingenious arrangement is adopted by which, when the bridge is turned end for end, the name plates for signal levers and instruments automatically change and correct themselves.

The hydraulic accumulator contained in the centre cylinder is weighted to produce a pressure of 700 lbs. on the square inch. The steam-engines and boilers to charge the accumulator are all in duplicate, and are situated in an engine-house erected at the north end of the staging. Each engine is designed to give 20 actual HP. The bedplates serve as receiving-tanks for the exhaust water returned from the hydraulic gear. A mixture of glycerine and water is used as in the Hull bridge. The boilers are internally fired and of the multitubular type. There are two settling-tanks 28 feet long by 8 feet by 3 feet. These are necessary owing to the river water being heavily charged with warp, which, however, settles after three or four days.

The operations of opening and closing the bridge are as follow :—

1st. All the signal-levers being "at danger," the bridge-man pulls over lever A working the knuckles, and the ends of the bridge rise about $\frac{3}{8}$ inch.

2nd. He then pulls over the lever B, causing the resting blocks to slide clear of their bearings.

3rd. He next puts back lever A, when the knuckles relax, leaving the bridge supported only by the centre pier.

4th. The catch-bolts are then withdrawn by pressing the lever C, and the bridge is free to open.

5th. The bridge is opened by turning the handle D in the direction in which it is intended that the bridge shall revolve.

The bridge is closed in a similar manner, the ends being gently brought up, by the spring-catches, and further proved in position, by projections on the cast-iron bearings, which engage with the knuckle shoes when raising the bridge; this arrangement is most useful. The resting-blocks being inserted and the knuckle gear released, the bridge is fit for railway traffic.

The signal levers are interlocked with a controlling lever which inserts bolts into the resting-blocks and shore spans, so that unless all are in true position the signals cannot be lowered. This movement also makes electric contact between the bridge and the shore.

The bridge can be opened in one minute and a-half.

Lighting.—The bridge is provided with oil lamps showing red lights at the centre of each span and over the piers; a head light at the top of the valve-house having red and green dioptric lenses, indicating by night whether the bridge is open or closed to the river.

Erection.—The swinging span was erected on the permanent staging, which was covered with temporary timbers at the required level. No special difficulties were entailed during this process, the three centre bays being erected and riveted first, and then lowered on to the distributing girder; the roller-paths, live ring, &c., having been already placed in position and carefully adjusted. The remaining bays were then added by degrees and riveted. When the blocks on which the girders were erected with a reverse camber of 1½ inch were removed, the average droop at the ends was 1⅝ inch, the bottom of the span being nearly straight. This droop is very slight bearing in mind the shallow proportions of the girders. The set of diagonals pointing towards the ends of the bridge were not riveted till after the erecting-blocks had been removed, as, owing to the droop at the ends, and the compression of the verticals when the bridge is swinging, these bars require to be appreciably shorter, in order to be tight and ready to take tension, when the bridge is closed.

Variations in temperature have a marked influence on the girders, careful observations of which have been taken; the greatest vertical movement was ⅞ inch between 52° and 98° Fahrenheit. The cylinders were sunk from temporary staging. The lower lengths, having been bolted together and calked, were lowered on to the bed of the river, and fresh lengths were added from time to time. The clay was excavated from the interior by a Priestman's grab, which removed the core, divers having to be employed to break down the material from the sides ready for the grab. The cylinders were kept continually filled with water, as the bottom of the river is treacherous, the top-clay being puffy and soft. Cast-iron weights caused the cylinders to follow the excavation. The required depth having been reached, the cylinders were filled with cement concrete lowered in a box having a trap-door bottom.

The cylinders of the centre pier were tested with a dead load of 186 tons, equivalent to 4·78 tons per square foot of base, including concrete, &c., applied for seven days, the average settlement being $1\frac{1}{4}$ inch. Those of the intermediate piers were tested with 214 tons, equal to 4·5 tons per square foot of base for twenty-one days, and the average settlement was $4\frac{3}{8}$ inches, the amount per day gradually diminishing to nothing.

The permanent staging for the protection of the bridge is 293 feet long, having rounded ends. It is formed of 13-inch piles securely braced together and decked over on the top. The top is 9 feet above high water. The headway under the opening spans is 15 feet at ordinary high-water spring tides.

The setting out and construction of the bridge were very satisfactory. The ends of the swing portion have the required 2 inches clearance between the shore spans almost to a nicety. Mr. J. P. Cooper, Assoc. M. Inst. C.E., was Resident Engineer in charge of the bridge.

The swing bridges and the greater part of the ironwork were manufactured by Messrs. Handyside and Co. of Derby. The Horsley Company, the Butterley Company, Mr. John Butler of Leeds, and Messrs. Eastwood, Swingler and Co., also constructed bridges for the line. Sir W. G. Armstrong, Mitchell and Co., supplied the hydraulic machinery for the swing bridges, and Messrs. Lucas and Aird were contractors for the line.

In conclusion, the Author would offer his best thanks to Mr. W. Shelford, M. Inst. C.E., who has willingly and unreservedly allowed the details and experience of the foregoing works to be described, and for the privilege of bringing under notice details with which he has personally been connected.

The Paper is accompanied with numerous diagrams and small scale drawings, from which Plates 9 and 10 and the cut in the text have been prepared.

[APPENDIX.

APPENDIX.

The general terms of the specification in a compressed form under which the ironwork was constructed are as follow:—

All holes in main girders to be drilled or punched $\frac{1}{8}$ inch less in diameter than the finished size, and after the girders are put together rimered out to full size.

The rivet holes in the various members must coincide, so that when the plates, &c., are put together, a rivet $\frac{1}{32}$ inch less in diameter than the holes can enter without the use of the drift.

All plates to be machined at the edges.

All forgings to be made from the best hammered scrap iron.

The iron used must be of such quality as to meet the following requirements as shown by test samples:

Description.	Breaking weight per Square Inch not less than	Contraction per Square Inch original Area not less than
Plate Girders.	Tons.	Per cent.
Plates with grain	20	15
Bars up to 10 inches wide . . .	20	20
Tee-irons, angle-irons	20	20
Lattice Girders.		
Bars	24	20
Angle-irons, tee-irons, channel-irons	22	15
Plates (with grain)	21	10
„ (cross „)	18	5

Rivets must be capable of being bent double cold.

Castings.—Castings to be run from such a mixture of metals as shall produce a tough strong grey iron.

Three test-bars 3 feet 6 inches long, 2 inches deep, and 1 inch thick, to be run from each melting from which castings are made.

Test-bars to be placed bottom face downwards between bearings 3 feet apart in the clear, and must support, without breaking, a weight of 28 cwt. applied at the centre with a deflection of not less than $\frac{5}{16}$ inch, otherwise the castings represented by the test-bars will be rejected.

Some little difficulty was experienced with reference to the protection of the ironwork from rust, and a variety of mixtures of tar, pitch, tallow, resin, &c., were tried; also "tar varnishes" by different makers with varying success. In the Author's opinion good tar, thinned if necessary with naphtha or petroleum is next best to good paint.

Some paints will not dry for years on ironwork if applied over fresh tar, and if paint is put on first the tar will dry, but will permanently soften the paint underneath, and they both will be rubbed off together.

OBITUARY.

FLEEMING JENKIN, LL.D., F.R.S., V.-P.R.S.E., was born in Kent, on the 25th of March; 1833. His father, Charles Jenkin, of Stowting Court, Kent, was a captain in the Royal Navy; his mother, H. C. Jackson, was a Scotchwoman, and a novelist of some distinction. Henry Charles Fleeming Jenkin, their only child, was taken to Scotland at the age of seven, where he was put to school at Jedburgh and later at the Edinburgh Academy. At thirteen he went to the Continent and continued his school-life, first at Frankfürt-am-Main and then in Paris, which he left, after the Revolution of 1848, for Genoa. There he passed through a course in arts at the University, taking his degree in 1850, and there also he began his engineering career in a locomotive shop under Philip Taylor of Marseilles. Next year he returned to England and entered on an apprenticeship of three years under Messrs. W. Fairbairn at Manchester. His first employment as an engineer again took him to the Continent, on a survey for the proposed Lukmanier railway in Switzerland, under Mr. Hemans; after that he found work with Messrs. Penn at Greenwich, and later with Messrs. Liddell and Gordon, in railway engineering. From their service he passed, in 1857, into that of Messrs. Newall of Birkenhead, who were then engaged in making the first Atlantic cable. Jenkin was entrusted with their chief engineering and electrical work. He superintended machine-construction in the factory, designed machinery for paying out and picking up cables, fitted up their cable ships, and took charge of the electrical testing. His connection with Messrs. Newall directed his activity into the line it was afterwards to follow with most signal success. So early as 1859 his authority as a specialist was recognised by his being called to give evidence before the Royal Commission on Submarine Telegraphs. He remained in Messrs. Newall's employment during the manufacture of part of the first Atlantic cable, a cable from Singapore to Batavia, and several important Mediterranean cables, in the laying of which he took a share.

For one of these, the cable from Malta to Alexandria,[1] Mr. H. C.

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[1] Minutes of Proceedings Inst. C.E., vol. xxi., p. 493.

Forde had acted as engineer under the British Government, and with him, in 1861, Jenkin entered into partnership as telegraph and general engineers. The partnership lasted for seven years. During this time he acted as Engineer-in-Chief of Reuter's, the French Atlantic and the German Union Telegraph companies, and the Rouen Waterworks. He went abroad with the cables to direct operations during the laying, and the large experience which he had by this time gained led the Government to employ him as consulting engineer with regard to submarine cables during the transfer of the telegraphs to the Post Office. In this capacity he tested all the cables which were then taken over.

While still at Newall's Jenkin had the good fortune to come in touch with Sir William Thomson, under whose encouragement he began to write on scientific subjects in 1859, and in 1861, when Thomson proposed the formation, by the British Association, of a committee to determine standards for electrical measurements, Jenkin's technical skill and boundless energy well qualified him for the part of Thomson's lieutenant. He was made secretary of the committee; in conjunction with Clerk Maxwell he took a large share in its classical experiments, and for many years wrote its reports. It would be hard to overestimate the value of this work. By establishing practical units in which electrical magnitudes could be expressed, the committee did much to bridge the gulf which had, up to that time, separated the electricity of the schools from the electricity of the cable-factory and the telegraph-station. It gave a common standing ground to the mathematician and the engineer, who at once found themselves of mutual advantage. It stimulated the purely scientific side of the subject by enriching and simplifying its vocabulary, and by placing in the hands of physicists new instruments and methods of research. It raised electrical engineering from empiricism to the rank of applied science; and it paved the way for that rapid progress in the applications of electricity which is so marked a feature of the present time. The results of the committee were eagerly accepted by British electricians, and two years ago they were practically ratified by the International Conference at Paris, to which Jenkin was sent as one of the English representatives.

The connection with Sir W. Thomson, then usefully begun, ripened into a close personal friendship and professional association which lasted till the close of Jenkin's life. In 1860 they obtained their first joint patent, for improvements in telegraphic communication. Its main feature was the system of "curb-sending," that is to say, the production of an electric signal by connecting the line first to one pole of the battery, and immediately after that, for a shorter time, to the other pole, a process which leads to greater sharpness of signals, and consequently to greater speed of sending in submarine lines. The form of "curb-sender" known to electricians of the present day was developed in two later patents by Thomson and Jenkin. In 1865 an agreement was concluded between Sir W. Thomson, the late Cromwell Fleetwood Varley, and Fleeming Jenkin, by which they joined forces with regard to their telegraphic inventions. To the common pool Varley contributed the highly important plan of signalling through condensers, and Thomson his invention of the mirror galvanometer, to which he afterwards added the siphon recorder. Each member of the triumvirate threw in minor inventions from time to time; and as their patents covered the only methods by which long submarine cables could, or still can, be practically worked, their apparatus was used by all the great companies, and the partnership proved extremely profitable. To Jenkin was entrusted the commercial management. In this, as in other affairs, he showed himself to be not less a man of business than a scientific theorist and a practical engineer, and his excellent tact and thorough fairness secured for the patents a freedom from litigation remarkable in so valuable a monopoly.

Another partnership with Sir W. Thomson, distinct from the above, was formed after Jenkin went as professor to Edinburgh. By this they agreed to act jointly as engineers to cable companies, in superintending the construction and laying of submarine lines. The Western and Brazilian, the Platino Brasileira, the West India and Panama, and very lately the Mackay-Bennett Atlantic cables, were amongst those made to their specifications, and laid under their charge—in some cases under their own eyes.

So long, close, and various an association between men of the stamp of Thomson and of Jenkin could have no basis but a conviction of mutual helpfulness and esteem. Of his great obligations to Thomson, Jenkin was ever ready to speak. But no partnership with Jenkin could be of benefit to him only, and whatever his debt to Thomson, he must have had the satisfaction of feeling that some part of it was repaid in the service as partner which, to say nothing of his knowledge and skill in electrical matters, he was qualified to render by his mechanical training and wide capacity for affairs.

In 1866 Fleeming Jenkin was appointed Professor of Engineering in University College, London, but resigned the post in 1868 to take the Chair of Engineering then founded by Sir David Baxter in the University of Edinburgh, which he filled to his death. His teaching was highly successful, original in conception, and altogether characteristic of the man. Seizing the salient points of his extensive subject, he passed from one to another with a rapidity that left little breath in the boy fresh from the country, and used to the drudgery of school drill. But if fast, the teaching was clear and thorough, shirking no difficulties that were natural to the subject, and presenting none that were artificial; and the boy, if he was good for anything, was bound to follow, though panting. Each part in turn was illustrated by a host of numerical examples—practical questions set for solution at home in forms drawn from the teacher's experience. These at once clinched the teaching of the lecture-room, and accustomed the lads to look on the theory they were learning as no mere abstruse piece of mental gymnastic, but as a tool for daily use in the drawing-office and the workshop in after life. A notable feature of his style was the comparative absence of mathematical form. He had himself a distaste for algebra, which led him to employ it sparingly, except in the simplest applications; but he managed to do this with little if any sacrifice of logical completeness or precision in his exposition of engineering theory. In later days some of his pupils came to realize that they had all the while been learning mathematics without knowing it. They learned, too, the useful lesson, not always taught or exemplified by professors, that engineering theory in its most valuable results may be brought within the grasp of persons to whom the use of symbols is but little familiar. In Jenkin's hands the work of the class was certain not to fall into set grooves. His teaching was no easy repetition from year to year of stereotyped lectures. A book or paper would suggest a new mode of presentation, or the idea would occur without tangible inspiration, and immediately he would write out afresh a whole section of the course with all the zest of a novice. When the Christian Knowledge Society's treatise on "Matter and Motion," by Clerk Maxwell, was published, it took possession of Jenkin, dominating him for days, and under its inspiration, he remodelled his whole treatment of dynamics.

To his students, the work of the engineering class was absorbing and exacting; to himself, carefully and thoroughly as he discharged it, it was only one of many outlets for his buoyant activity. His work as a telegraph engineer has been already noticed: alongside of it and of his professional duty, he found time for lectures and addresses, for general consulting and legal practice, for writing scientific papers and textbooks, as well as articles of more general interest for reviews and journals, for successful agitation in the direction of sanitary reform, and for a host of inventions which culminated in the system of electrical transport to which he gave the name of "Telpherage." With all this, he was a man of the widest sympathies and most varied knowledge in literature and art; "the best talker in London," as one of his friends has said; "knowing more of the construction of plays than any man in England," according to another, something himself of an artist and an actor, and more than something of a stage-manager; a critic, and the close friend of writers; an authority on Greek plays, and English rhythms; an economist and a sportsman. His review of the "Origin of Species" led Darwin (who frankly acknowledged its value) to abandon his argument on variation by sports. His analysis of the atomic theory of Lucretius has been quoted with approval by Munro, whom he was reviewing, and by many later commentators. Another review, on a book of medical statistics, had the rare compliment of being reproduced in the second edition of the work. These and more papers by Jenkin in the "North British," the "Edinburgh," the "Saturday," and other reviews, have no need to depend for their interest on the curious fact that one man should have treated such diverse themes, and he a man with a life-work full (one would have thought) to overflowing, outside of literature. More even than his writings, Jenkin's talk displayed the variety of his interests and the readiness with which the flash of his restless intelligence could be turned to lighten up any subject, however far from his usual thoughts. It was impossible to take him unawares. Ready on the moment to produce a theory of things in general or in particular, he would lay it down with a dogmatism which was half jesting, half serious, but wholly good-natured and full of wit and point. His versatility would have been dangerous had it not been tempered by strong common-sense, and by his power of giving concentrated application to any matter he took seriously in hand.

In this notice it is impossible to do more than mention, and that very briefly, the leading features of Jenkin's technical and scientific work. His English patents, dating from 1860 to within a few days of his death, numbered thirty-six. A few of these were taken out jointly with Thomson, or with one of the younger men who found Jenkin as willing to be a colleague as a master, but most were wholly his own work. The greater number were for applications of electricity to telegraphs, and, in the last years especially, to locomotion; but his faculty of invention ranged over a wide field, and has left its mark in bridge-work, in hydraulics, in mechanism, and in heat-engines. His patents for bridges in 1861 and 1869 deal with the braced arch, the analogue of a suspension bridge made rigid by cross-bracing, with top and bottom members both in compression, instead of subjected to opposite stresses as in the common girder. The economy of material possible in this form, and the treatment of the problems which it presented, were further elucidated by him in a Paper "On Braced Arches and Suspension Bridges," read before the Royal Scottish Society of Arts in 1869.[1] In this connection, another Paper may be mentioned, "On the Practical Application of Reciprocal Figures to the Calculation of strains on Framework," published the same year in the Transactions of the Royal Society of Edinburgh.[2] He there exhibited the graphic method of treating stresses, now familiar, but then scarcely known to engineers, by examples, which made its practical value obvious; by this, and by always making it a marked feature in his teaching, Jenkin did much to acquaint the profession with its use.

His knowledge of thermo-dynamics led Jenkin to realize clearly the economy which would result if heat-engines could be made to burn their fuel internally, and thereby allow the working substance to be carried through a range of temperature much larger than is practicable in the steam-engine. With this object he strove to apply Stirling's Regenerator to gas-engines, and engines burning coal within a closed chamber under compression. His earliest effort in this direction appears in a patent of 1874; the engine figured there was the subject of fruitless and disheartening experiments during several years. In 1881, with one of his assistants, he brought out three new patents, full of practical details, and giving evidence of much labour. The engines proposed were essentially of the Stirling type, but without an external furnace, and with provision for the combustion of fuel within the displacement-chamber, the products of combustion of the fuel forming the working substance. Feeders were provided for introducing air and fuel, and an equilibrating arrangement for discharging a portion of the compressed products at every stroke. Experimental engines were constructed under the patents: these showed the practical impossibility of realizing the invention on any moderately small scale, and Jenkin was reluctantly forced to the conclusion that the economical heat-engine of the future would require for its development a larger capital than he was disposed to apply. In a lecture on "Gas- and Caloric-Engines," delivered before this Institution in February, 1884, as one of the course on "Heat in its Mechanical Applications," he has indicated what difficulties lie in the way: in the same lecture he has stated clearly the grounds for his undiminished faith that the steam-engine will ultimately be supplanted by an engine which gets its heat by the internal combustion of gas. This lecture, one of the latest pieces of his work, is highly characteristic; alike in its thoroughness—for, with the appendices, it forms nothing less than a treatise on the subject—in the fairness and frankness of its reference to the two rival inventors who have met with most success, in the modesty with which it touches on his own labours, and in its fulness of detail and grasp of general principles.

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[1] Transactions of the Royal Society of Arts, vol. xviii., p. 135.

[2] Transactions of the Royal Society of Edinburgh, vol. xxv., p. 441.

An excellent invention was his "Constant Flow-Valve for Water and Gas," patented in 1876, described by him before the Scottish Society of Arts,[1] and by Professor Unwin in the article on "Hydromechanics," in the new edition of the "Encyclopædia Britannica." The valve is an automatic regulator, with the object, which it achieves very exactly, of maintaining a uniform volume of flow, no matter what variation may occur in the pressure under which the discharge takes place.

In pure mechanism his "nest gearing," patented in 1883, and described in the Report of the British Association[2] for that year, supplied a means of transmitting power by rolling contact without being open to one main drawback of other forms of frictional driving-gear. In most other arrangements the rollers between which motion is to be transmitted are pressed against one another by force applied to the bushes in which they turn, a plan which leads to much wear and loss of power. Jenkin, with whom the frictional efficiency of machines was a favourite study, saw that this could be avoided by certain modes of symmetrical placing, by which he grouped the rollers into what he called "nests." The designs are often of much beauty, and Jenkin revelled in the variety of forms the idea was capable of taking in his hands. Only a few days before his death the specification was completed of a new type of friction gear, not unlike the "nests," of which he was joint inventor. Other mechanical inventions were certain constructions of centrifugal speed-governors, and a brake-strap for application to telegraph cable-work in 1866, which adjusts itself automatically so as to apply no more than a specified amount of retarding force to the drum which it clasps.

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[1] Transactions of the Royal Society of Arts, vol. ix., p. 570.

[2] Report of the British Association for the Advancement of Science, 1883, p. 387.

In later years, however, his interest as an inventor was mainly concentrated on the system of electrical transport, which he called "Telpherage," so recently and fully described by himself, that only the shortest mention of it need be made here. The "Telpher" line is a flexible conductor of electricity, supported on posts, and made strong enough to carry an electric motor and a train of light trucks or buckets, which hang below it. The line is in short sections, electrically distinct, and the train, longer than a single section and itself a continuous conductor, bridges over the interval between successive sections as it passes. Power comes from a fixed engine and dynamo at any convenient station, and arrangements are added for automatic government of speed, for shunting, for the use of an absolute block-system, and so forth. The trains run slowly, and need no attendants to travel with them. This, and the light construction of the line, as well as the saving in ground space, makes the "Telpher" railway cheap, and Jenkin anticipated that his invention would find extensive use as a feeder to ordinary railways, and in carrying minerals, grain, &c., in mines, granaries, and docks. His first patent for "Telpherage" is dated 1882. In the three years that succeeded he followed this up by more than a dozen others, covering point by point of his system in detail. Finding that Messrs. Ayrton and Perry were also at work on the application of electricity to locomotion, he joined forces with them, and organised the "Telpherage" company, by whose help he was able to conduct, on a working scale, the costly experiments which were necessary before the plan could be brought into operation. These trials were directed by Jenkin, who threw himself into the work with even more than his usual inventive industry, executive ability, and determination to overcome all obstacles. After much strain and anxiety he had the satisfaction of knowing, before he died, that the first step towards a practical realization of his hopes was ensured, and his friends are sanguine that his work was so far perfect that its results will survive his loss.

A sharp illness in the winter of 1883 gave warning that he was overtaxing even his power of work. He recovered, to all appearance, completely, and fell to again with little if any abatement of zeal. His intimate friends knew nothing of illness, when, last June, they were shocked to hear that he was dead. A slight operation of surgery, submitted to that he might be able, as in former years, to seek his favourite recreation on the moors, was followed by the symptoms of blood-poisoning, and he died after a day or two of illness, on the 13th of June 1885 when only fifty-two years of age, and in the very height of his usefulness.

Fleeming Jenkin's work as an educator was far from being bounded by the walls of his class-room. His view of what the training of an engineer should be has been laid down on several occasions, especially in an address on "Technical Education,"[1] a subject in which he further showed his interest by giving evidence before the Select Committee in 1868 and the Royal Commission in 1883, and by taking an active part in the management of the Edinburgh Watt Institution. He contended with much vigour and force that the system of apprenticeship should be maintained, that attempts to substitute for it the practice possible in a merely educational workshop were futile; but that it required, as preparation, such training in mechanical science as could and should be given in the common universities and schools. He deprecated the continental system of special technical colleges; urged that the Universities should offer a complete theoretical course and grant degrees in engineering; that on the other hand engineers should look for a fair knowledge of theory in the pupils they took, and give a preference to those who came prepared. He insisted that mechanical drawing should be taught in primary schools, as a first requisite in the education of every working man. In a Paper read at the Educational Conference in the Health Exhibition of 1884, he laid down the principle that the work of a scientific laboratory should be training in the art of measurement, and described his idea of what a university laboratory might effect as an adjunct to the lecture-room in the higher education of engineers.[2]

His efforts after social reform found another opening in the field of sanitary engineering. Not content with explaining the best methods of domestic sanitation, and with popularizing the subject by lectures and tracts, and recognizing that the only security for the ordinary householder lay in having his drains submitted to periodical examination by a skilled engineer, Jenkin invented in 1877 a scheme of house-inspection, modelled on the Manchester Boiler Association, founded by Sir W. Fairbairn. His idea was that, as members of a co-operative society, the public could secure the services of a young sanitary engineer, working under the eye of a professional man of longer standing, to report annually on the condition of their houses, and to advise in the repair of whatever was defective. Jenkin gathered round him a committee of prominent citizens, drafted rules, beat up subscribers, and in a few weeks from the day the idea occurred to him, the Edinburgh Sanitary Protection Association was fairly launched. It was found to meet a real need, and its success has been such that other societies on the same lines have been formed in London and in most of the great towns. Jenkin served as consulting engineer to the parent association, and to several of its offspring, until his death.

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[1] Transactions of the Royal Scottish Society of Arts, vol. viii., p. 1.

[2] "The Health Exhibition Literature," vol. xv. Conference on Education. "On Science Teaching in Laboratories," p. 16. London, 1884.

For employment as a scientific witness in the Scottish Courts his position in Edinburgh gave him ample opportunities, and no one could put a case better before a jury. But Jenkin was too honest to be a good partizan unless his conviction lay on the side he supported; delighted as he often was to support a paradox as an exercise in dialectics, he would never, where serious issues were at stake, add his weight to the side he did not believe in. He usually shrank from the work of a witness, but in recent years found occasional occupation as assessor on the Bench, a post for which his taste and talents made him eminently fit. At International Exhibitions his services as a juror were in frequent request; to other qualifications for the office he added that of being an accomplished linguist—a hereditary gift for languages having been fostered by his boyhood and youth spent in Germany, France, and Italy.

The list of his scientific papers numbers about forty; of these most deal with electricity and its applications; but the rest show, not less than his patents, the versatility of his powers. His book on "Electricity and Magnetism," published as one of Longmans' scientific series in 1873, has passed through many editions, and been translated into German and Italian. The subject it treats has advanced by leaps and bounds during the twelve years which have since elapsed; but his work holds its place, and remains the standard elementary text-book. It was, in fact, the first systematic exposition of that new electricity to which the labours of the British Association committee had given form, the science of the practical electrician, which was, as Jenkin himself said, more scientific than the science of the older text-books. Some years later, at the solicitation of the Society for the Promotion of Christian Knowledge, he wrote a primer on the same subject. The article "Bridges," in the new edition of the Encyclopædia Britannica, was also from his pen, and was republished as a separate volume. Of his miscellaneous scientific papers, only one or two can be noticed here. An experimental research on "Friction," published in the Philosophical Transactions for 1877,[1] showed that the coefficient of friction between metals, and between metal and wood, is not, at very low speeds, independent of the relative velocity of the rubbing surfaces, and supported the view that there is continuity in value of the friction between surfaces in relative motion, with the usually greater friction between the same surfaces at rest. In another research the phonograph of Edison, then newly invented, was successfully applied to the harmonic analysis of vowel sounds—a task which had, up to that time, been attempted only by Helmholtz's method of using resonators to detect the several constituents of a compound tone. The results of this inquiry were published in the Transactions of the Royal Society of Edinburgh for 1878.[2] Of all Jenkin's papers, the most remarkable was his "Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in two parts in the Transactions of the Royal Society of Edinburgh, for 1876–8,[3] a piece of work whose value the Society recognized by the award of its highest distinction—the Keith gold medal. This paper was inspired by the study of Reuleaux's "Kinematics of Mechanism"; but the turn taken by Jenkin's thoughts was so original that, did he not acknowledge it, the influence of Reuleaux would scarcely be suspected. Jenkin saw that the value of Reuleaux's work lay, not in his cumbrous notation and nomenclature, but in his central conception of every mechanism as a self-contained whole—a complete chain of connected parts. But he saw that to stop short, as Reuleaux does, before the merely kinematic aspect of machinery, is to sacrifice the very essence of the gain which Reuleaux's conception brings; and he quickly passed to complete the analysis from the dynamic point of view. He added the elements which were required to turn Reuleaux's kinematic chain into a full machine, receiving energy and doing work, and, as an application of the idea, showed that it led at once to the solution of the problem—hopelessly complex if attacked by any earlier method—to calculate the precise waste by friction which the power passing through a machine undergoes. This application gave the title to his Paper;

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[1] "On Friction between Surfaces moving at Low Speeds." By Fleeming Jenkin and J. A. Ewing, p. 509.

[2] "On the Harmonic Analysis of certain Vowel Sounds." By Fleeming Jenkin and J. A. Ewing, vol. xxviii., p. 745.

[3] Vol. xxviii., pp. 1 and 703.

but the Paper itself is of much wider scope than its title would lead one to expect. He shows that any complete machine is dynamically equivalent to a frame, composed of struts and ties, in which the stresses are those which exist at the several joints between the moving parts of the actual machine. He points out how this "dynamic frame" may, in imagination, be constructed, and how, for co-planar motions, it may readily be drawn. By an obvious application of the method of reciprocal figures to this frame, the relation of the resistance overcome by the machine to the effort exerted in driving it is then solved without difficulty. Any one of the stresses being known, all the rest become determinate, and the pressure at every joint and bearing is found with equal ease. Jenkin goes on to show how the dynamic frame is to be drawn when the friction of the moving pieces is taken into account, and also the resistance which their inertia makes them offer to every change of motion. The second part gives numerical results, got by applying the novel methods of calculation to a steam-engine of practical proportions, which is supposed to run under various conditions of load and speed.

Fleeming Jenkin became a Member of this Institution in 1868. He was also a Member of the Institution of Mechanical Engineers. He was elected a Fellow of the Royal Society of London in 1865. The Edinburgh Royal Society made him a Vice-President in 1879. In 1871 he was President of the Mechanical Section of the British Association. The Société Professionelle d'Hygiène of Paris elected him an Honorary Member. In 1883 he received the degree of LL.D. from the University of Glasgow. His latest honour was the posthumous award of a gold medal for Telpherage in the International Inventions Exhibition held this year.

In 1859 he married Anne, daughter of the late Alfred Austin, C.B. She survives him with three sons, into whose sports and labours, from childhood to maturity, it was his delight to throw himself with the hearty participation of a brother or friend. Outside of his family he was a man easy to admire, but hard to know: it was only after long acquaintance that one entered the inner chamber of real intimacy. Many men who thought they knew him never got so far, but those who did found in his fine simple humanity and Christian loving-kindness a claim to their esteem stronger than any quality of intellect. His transparent honesty would tolerate no shadow of a lie, least of all in himself. To his friends he was frank, sympathetic, helpful, often affectionately severe. The hand held out to younger men on lower rungs of the ladder—the anxiety to secure for any who worked with him the fullest share of credit, the delicate little conspiracies in which he plotted with his wife to do some unlooked-for kindness to those they loved, less prosperous than themselves—these are things which it is good to have seen and known. Other men have achieved higher eminence and done more enduring work, but to few is it given to leave a more various impress, or to have their memory cherished with a tenderer regard.

GEORGE GORDON PAGE, son of Thomas Page,[1] M. Inst. C.E., was born in London in the year 1836, when his father was the Acting Engineer of the Thames Tunnel. He was educated chiefly at King's College School, London, and entered his father's office when the Chelsea and the Westminster Bridges were in course of construction. At that time he took the lead in two or three railway surveys, but soon acquired a private practice of his own, and was entrusted with the widening and improvement of several bridges of minor importance. In 1867 he designed and superintended the construction of a new bridge at Myton over the Swale, in Yorkshire, and later one over the Tyne at Haltwhistle, in Northumberland, both on his favourite principle, namely, the iron arch of wide span. He was subsequently appointed Engineer to the Margate Pier and Harbour Company, a position gained by competition. After some years of delay, and frequent modification of designs, he commenced, in 1875, the new pier-head, which, with its promenade and other accessories, was completed about the year 1878. It covers a large area of sea, and is probably the most popular resort of the kind, as well as the most profitable to its proprietors. He also rebuilt the landward end of the jetty after its destruction by a storm.

During his career, Mr. Page initiated and planned many schemes for sea-board jetties, designed to afford berths for vessels in any state of the wind or tide. In 1873, and subsequent years, he made the surveys and directed the construction of the Ravenglass and Eskdale Railway, in Cumberland, a 3-feet gauge mountain line. From 1877 to 1881 he was engaged upon the Skeldergate bridge, over the River Ouse, in the City of York, and the several approaches thereto. This bridge is of iron arches, springing from massive stone abutments and piers; a portion of it on the bascule principle, to accommodate navigation, is made to open by means of hydraulic machinery. The introduction of this mechanism into an ornamental bridge entailed engineering difficulties which were skilfully dealt with. The bridge and its accessories were designed in early fifteenth century Gothic, and the greatest care was bestowed upon every detail. Mr. Page was an excellent draughtsman and colourist, and has left behind many drawings to testify to his skill.

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[1] Minutes of Proceedings Inst. C.E., vol. xlix., p. 262.

During the last year of his life he was a confirmed invalid; the consumptive maladies, which ended fatally on the 13th of July 1885, kept him wholly confined to the house in the previous winter. He was elected an Associate of the Institution on the 7th of February, 1865, and was transferred to the class of Members on the 15th of January, 1878.

NATHANIEL ST. BERNARD BEARDMORE, the eldest son of Nathaniel Beardmore,[1] M. Inst. C.E., Author of the well-known "Manual of Hydrology," was born in Westminster on the 20th of October, 1848. His early years were passed at a preparatory school at Rochester, from which he was removed to Felsted School in Essex, where he remained till December, 1864. Young Nathaniel often accompanied his father in inspections of works on the River Lee, and in January, 1865, entered the office of his father, to whom he was soon afterwards articled for five years. During part of this period he attended lectures on physics, mechanics, geology, and chemistry, at the Royal School of Mines in Jermyn Street, and was further instructed in mathematics by a private tutor. He was admitted as a Student of the Institution on 19th of November, 1867. Whilst serving his articles he was much engaged on the reconstruction of locks, weirs, and other works on the River Lee, residing for some time at Limehouse with the resident engineer during the reconstruction of the entrance lock into the Limehouse Cut, and in a measure he superintended the reconstruction of King's Weir on another part of the river. He wrote a description of the latter work, which was read at a meeting of Students, and for which he received a Miller Prize in 1873. He further gained considerable experience on works connected with the Essex sewers, of which his father held the appointment of engineer; he was also engaged on surveys in various parts of the country. At the expiration of his pupilage, in May, 1870, Mr. Beardmore remained as an assistant in the office of his father, and was engaged in connection with the River Lee and on many other water and drainage works. In the year 1871 he superintended the dredging and cleaning out of a mill-stream at Broxbourne, in Hertfordshire, which, owing to its having to be done in accordance with an award, obtained by a law-suit, required great care and attention to levels. During the latter part of the year 1871 he was employed by Mr. R. H. Twigg, M. Inst. C.E., on the Parliamentary survey for the proposed "South Midland Railway," for which Messrs. Brunlees and McKerrow and Mr. A. C. Pain, MM. Inst. C.E., were the chief engineers. In 1872 he assisted his father on an extensive survey and observations on the tidal portion of the river Thames, for an enquiry as to a proposed lock below Richmond. On the death of his father in August of that year he succeeded to the latter's partnership with Mr. John Hickman Barnes, M. Inst. C.E., and practised at 30, Great George Street, Westminster, S.W., being engaged on the extension of the Llanelly Waterworks, comprising the construction of a large additional storage reservoir and the necessary connections therewith, and on various drainage matters. He was elected an Associate of the Institution of Civil Engineers on the 2nd of December, 1873, and was also a Fellow of the Royal Geographical and of the Royal Meteorological Societies, and a Member of the Geologists' Association.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 256.

In October, 1875, he was appointed Assistant Superintendent to the Madras Harbour Works, under Mr. William Parkes, M. Inst. C.E., the Engineer-in-Chief. He was extremely proficient in marine surveying, and admirably filled the post. During the illness of the late Harbour Superintendent, Mr. James May, M. Inst. C.E., in the year 1876, he assumed the chief place of trust on the works with great ability and skill. The following order from the Secretary of the Government will show how his services were valued:—

PROCEEDINGS of the MADRAS GOVERNMENT PUBLIC WORKS DEPARTMENT.

"December 16th, 1876. No. 3,458.

"Nos. 422 and 423 under date the 16th December, No. 3,458.
"Establishment, No. 24.

"The Engineer-in-Chief of the Madras Harbour Works having brought to the notice of His Grace the Governor in Council that the post of Harbour Superintendent was filled by the Assistant Superintendent without extra remuneration during the illness of the late Mr. May, and up to the arrival of Mr. Thorowgood, a period of about four months, His Grace in Council has resolved that Mr. Beardmore shall be presented with a gratuity of 2,500 rupees in appreciation of the judgment and caution with which he filled a place of great responsibility in which he was suddenly placed. And he accordingly authorised payment of that sum being made to him and charged against Harbour Establishments.

"(True extract.)

"(Signed) G. W. WALKER, Major-General, R.E.
Secretary to the Government.

"To the Superintendent, Madras Harbour Works.
"To the Examiner of Public Works Accounts."

For some time after his arrival in India his constitution appeared to be proof against the frequent exposure to the tropical sun which his duties necessitated, but after five years a period of rest in England was advised. After his return, though his health appeared to be quite re-established, he was more sensitive to the sun than formerly, and in the autumn of 1884 there were unmistakable symptoms that greater care for himself was necessary. A three months' tour in the cooler parts of India appeared again to restore him, and he returned to his work at Madras with his usual energy, and without any immediately apparent ill effects. An attack of intermittent fever, however, which subsequently developed into typhoid, was more than his enfeebled constitution could withstand, and he succumbed to it on the 2nd of June, 1885, and was buried in the cemetery of St. George's Cathedral.

St. Bernard Beardmore was most indefatigable, untiring, and earnest in his work, and of a liberal and generous nature. Always upright and conscientious, he took the utmost interest in his profession, doing thoroughly anything he undertook, even to the minutest details. The following testimony to his worth appeared in the "Madras Times":—"The sad intelligence of Mr. Beardmore's death did not take the employees of the Madras Harbour Works by surprise; nevertheless, it was a great shock to those who had the good fortune to work under the orders of the late Assistant-Superintendent. It is not often that the relations between employer and employed excite such heart-felt grief at separation, and such respectful, yet deep, sympathy."

In domestic and private life, although of a very retiring and quiet disposition, he made himself especially endeared to all those around him, being always sincere and most unselfish in thinking of others before himself. His ever ready sympathy, thoughtful generosity, and genuine kindness will long be remembered.

ALEXANDER MORTON BELL was born at Leith in 1828, and served a regular apprenticeship with Messrs. Maxton, mechanical engineers in that port, whose business was afterwards taken over by Messrs. R. and W. Hawthorn, of Newcastle-on-Tyne, under whom his articles were completed. He then became a pupil of his brother, Mr. William Bell, M. Inst. C.E., at Bristol, and was afterwards engaged for some time as Assistant-Engineer on the Glasgow and South-Western Railway. He was employed by Messrs. Hutchinson and Ritson as their engineer in Cornwall, and on the widening of the Bristol and Gloucester Railway between Standish and Gloucester. He went out to India in 1859 for Mr. George Berkley, V.-P. Inst. C.E., as district engineer on the Nagpore branch of the Great Indian Peninsula Railway, and was stationed at Oomrawattee, where, although he had a severe attack of fever, he remained for three years. Returning to England, he was occupied on Parliamentary and other work for some time. In 1865 he went to Annan as engineer for Messrs. Waring, Brothers, and Eckersley, on the works of the Solway Junction Railway, including the long viaduct across the Solway. On the completion of this work, he surveyed and improved the arrangement of the tramroads of the Mount Sorrel granite quarries in Leicestershire, to the entire satisfaction of the owner of the quarries. He acted for Messrs. Barnett and Gale as their agent in the construction of the Isle of Wight Railway, and went to the Cape in 1874, as one of several engineers sent out at that time by Sir Charles Hutton Gregory, K.C.M.G., Past-President Inst. C.E., and was stationed near Port Elizabeth. While there, he had the misfortune, by his horse falling with him, to sustain a severe accident, which necessitated his return to England. He never quite recovered from this accident, and he was more or less of an invalid afterwards. Hoping to derive benefit from its milder climate, in the autumn of 1884 he went to Torquay, where he died on the 2nd of February 1885, after some weeks of intense suffering.

Mr. Bell was elected an Associate of the Institution on the 5th of March 1872. He was a pleasant companion, although at first rather reserved, and will be long remembered by those who knew him for his uprightness, his remarkably even temper, and his many good qualities.

MASSEY BROMLEY, the eldest son of the Rev. Thomas Massey Bromley, M.A., was born at Wolverhampton on the 15th of June, 1847. After receiving an education at Leamington College, he entered Brazenose College, Oxford, and graduated B.A. in 1869, proceeding to M.A. in 1872. Having a great taste for engineering, he, in February 1869, apprenticed himself for three years to Mr. Samuel Waite Johnson, M. Inst. C.E., then Locomotive Superintendent of the Great Eastern Railway, and went through a course of practical training in the locomotive and carriage works of that railway at Stratford. His ability, energy, and zeal, were so conspicuous that he was, in 1871, selected to inspect the construction of some engines, which the Avonside Engine Company were then building for the Great Eastern Railway. In urging forward the completion of these engines, and in tracing out, and if possible obviating, the causes of delay, he acquired a knowledge of shop management and organization, which afterwards proved very valuable. On returning to Stratford he was put in charge of the running shed repairs, and in October, 1874, shortly after Mr. William Adams, M. Inst. C.E., became Locomotive Superintendent of the line, Mr. Bromley was made Works-Manager, having charge of about two thousand men employed in repairing and building locomotives, carriages, wagons, and other plant. During the time Mr. Bromley held this position, the works were practically reconstructed, and fitted with the most improved machinery, and numerous labour-saving devices, amongst which may be mentioned hydraulic-riveting plant, power-cranes (in the erecting, wheel-turning, and carriage-fitting shops), twist drills, the best wood-working and saw-mill machinery, a complete system of 18-inch gauge-tramways, portable and flexible shaft drills, cast-iron patterns, moulding machines, &c. Great efforts were made to reduce the variety of type prevailing amongst the five hundred engines on the line. Standards, applicable to widely differing classes of engines were adopted, thus enabling finished parts, such as connecting-rods, axle-boxes, and even boilers complete, to be kept in store ready for any one of a large number of engines. In a few years the effects of these improvements became very apparent, the number of engines thoroughly repaired annually being largely increased, without corresponding increase in the total cost.

On Mr. William Adams leaving the Great Eastern Railway to take a similar position on the London and South-Western Railway, Mr. Bromley was promoted to the vacant post, on the 15th of

February, 1878. Though young and comparatively inexperienced for such an important position, the Directors soon marked their approbation by giving him a substantial increase of salary, and on his resigning office as Locomotive Superintendent, in August 1881, the Board presented him with £1,000, and retained his services as consulting engineer and scientific witness.

Mr. Bromley shortly afterwards entered into partnership with Mr. John C. Wilson. The firm of Messrs. Wilson and Bromley had established a good practice as general and consulting engineers, and Mr. Bromley was fast gaining an excellent reputation as a scientific witness in railway cases, when his career was suddenly cut short by death on the 16th of July, 1884. The crank axle of the engine of the train in which Mr. Bromley was travelling broke, while the train was running at full speed down an incline near Penistone, on the Manchester, Sheffield and Lincolnshire Railway. The driving-wheel tore up the rails, and the carriages were precipitated down the embankment near the Bull's Bridge Colliery. Nineteen passengers were killed on the spot, and sixty injured, several of whom were mortally hurt. Mr. Bromley was apparently killed instantly, but his injury was hardly perceptible, and his face wore a calm and placid expression.

Mr. Bromley was admitted a Student of the Institution in March 1870, and was elected an Associate in February 1874. He was a man of great energy and force of character, with an unusual power of acquiring and storing information. His love of work was intense, and his knowledge of the details of railway practice at home and abroad was remarkable. His memory will ever be cherished by all who knew him, especially by those who served under him, for he took a personal interest in all his staff, visiting them when ill or injured. An intimate friend has related that he "knew the Christian name and chief characteristics of nearly every workman and engine-driver on the Great Eastern line." After his death the engine-drivers subscribed to establish in his memory a bed in the London Hospital, an institution in which Mr. Bromley always took a great interest, and it may be added that much of his spare time was devoted to good work in the east end of London.

ALFRED BRACE CRUSE, born on the 21st of September, 1843, was the eldest son of Thomas Cruse, of Warminster, Wilts, land-agent and surveyor, and grandson of Joseph Brace, of Bath, who for many years was associated with Sir John Rennie, Past-President Inst. C.E., in engineering works. He was educated at Lord Weymouth's grammar school, Warminster, and then entered his father's office, in which he remained until July 1860, when he sailed for India, under a three-years' engagement with Mr. Alpin Grant Fowler, owner of coffee estates in the Neilgherry Hills. Having completed this engagement, and finding the position, after Mr. Fowler's death, not altogether advantageous, he removed to the city of Madras, where he gained the notice of some influential friends, and through them a situation with the Madras Railway Company as Inspector of Works, being stationed for two years at Cuddapah. In November 1866 he entered the service of the Madras Irrigation and Canal Company, under Mr. J. H. Latham, M. Inst. C.E., the Chief Engineer, and was first employed on the surveys of the Nellore branch, 100 miles in length, and subsequently as Assistant Engineer on the construction of the Pennair Anicut; also in laying out the line and on the construction of 8 miles of navigable canal, with its connected aqueducts, locks, bridges, and culverts. In 1871 he left the continent for Ceylon, having obtained an appointment as Assistant Engineer in the Public Works Department. At this time his principal work was constructing tanks and canals near Matara, in the Southern Province, upon which many hundred coolies were employed. In 1872 he had charge of the construction of the Elle Halle Tank, in doing which he found it hard work to make the surveys, and run the levels, through thick jungle (abounding with leeches innumerable), and to follow contours of the hill-sides some 30 or 40 miles round. This tank contained 240 acres of water surface. In the following year he was in charge of 400 miles of roads, besides buildings, and five taluks. He afterwards went to Denegama, where he completed the Ellawela irrigation works; superintended those in Upper Gangaboda Pattuwa; improved Kekanadure channels, to facilitate the distribution of water, and by December 1876 finished the repairs of the Denegama Tank.

In 1878 a famine occurred in Ceylon, which greatly taxed the powers of those in authority in providing food and labour. In 1879 Mr. Alfred B. Cruse was employed on some surveys for village tanks near Panadura, in the Western Province. He had also charge of the relief works near Colombo, upon which about two thousand villagers were employed. The work (one of several schemes surveyed by him) was a flood-outlet at Talpitiya, about 19 miles on the road towards Galle, by which lands in the Ratnapura and Kalutara districts were drained, and rendered capable of being cultivated. In 1880 he was at Beregama, surveying for a channel 7 miles long, running through dense jungle.

Early in 1881 he was, at the instance of his old chief, Mr. J. H. Latham, appointed divisional engineer of the lower part of the Madras Irrigation Canal, 82 miles, then in thorough working order; but some masonry works, including a large wharf and warehouse, as well as divisional office, docks, and foreman's hut, were in progress. Next he became Local Fund Engineer at Cuddapah, and had charge of 63 miles of canal, which was used for both irrigation and navigation, and in 1883 accepted a similar appointment at Ongole, 75 miles from Nellore. In 1884 he removed in the same capacity to Ellore, and in October of that year he obtained an advanced post, and went to Cocanada to take over the charge of his new position; but on returning to Ellore he was seized with cholera, and died, after a few hours' illness, on the 7th of October, 1884, leaving a widow and two children.

Twenty-four years' continuous residence in the East, especially in unhealthy parts of Ceylon, had caused Mr. Cruse to become a victim to temporary attacks of neuralgia and fever, but few men of an English constitution could so long have endured the Indian climate, with the amount of labour and responsibility which he sustained. He was regarded as a hard-working, intelligent, and trustworthy officer, of unimpeachable character, and was a valuable acquisition on any staff. He was warm-hearted, and kept up constant communication with his home friends.

WILLIAM JOHN JONES, third son of John Hodgson Jones, M. Inst. C.E., was born on the 26th of September, 1849. At the age of fifteen he entered his father's office, and went through the routine of drawing and estimating. In 1866 he was apprenticed for two years to Messrs. Blackwood and Gordon, marine engineers and shipbuilders, at Port Glasgow, and afterwards for three years worked in the erecting shop of Messrs. Handyside and Henderson, Finnieston Steam-Ship Works, Glasgow. In 1871 an accident occurred to a cast-iron gasholder tank at Trapani, belonging to the Malta and Mediterranean Gas Company, when the services of an engineer of practical experience were required. He was selected for the post, and carried out the work so successfully that in 1872 he was appointed Acting-Engineer to the company, with whom he remained for seven years. In 1879 he became Engineer and Manager to the Cerchi station of the Anglo-Romano Gas and

Electric-light Company at Rome, and was in their service at the time of his death, which occurred suddenly on the 10th of September 1884. He was elected an Associate of the Institution on the 6th of February, 1877.

WILLIAM FREDERICK MAYES, eldest son of William Millbanke Mayes, an experienced engineering surveyor, was born at Saddleworth in the year 1848. He was trained under his father, who was at the time engineer for the Compostelano Railway from Santiago to Carril—"Ferro-Carriles del Norvesta"—from Branuelas to Ponferrada, and from Ponferrada to Corunna. From January 1869 to August 1881 he was employed, generally as assistant to his father, on the Honduras Interoceanic Railway, for Messrs. Waring Brothers and McCandlish, at first to survey and locate the section from Puerto Caballos on the Atlantic to Potrerillos, a village in the interior some 50 miles distant, and subsequently in the exploration of the central portion of the line; also in making the working surveys under Mr. E. A. Drew, M. Inst. C.E., and Mr. J. Robinson, M. Inst. C.E. At this time it was said of him that "he used to select his camps with good judgment, and had the art of making himself and men comfortable under a variety of circumstances, and in obtaining whatever supplies the country naturally afforded. He was successful when surveying in running lines through thickly wooded and rough districts. His men worked for him cheerfully, and they became very expert in felling trees. Although not of a robust constitution, he got through a considerable amount of work. He spoke the Spanish language fluently." He returned to England on the abandonment of the project, and then for one year had charge to completion of a district of 15 miles of the Compostelano Railway, including heavy and important work for the concessionary, Mr. J. S. Mould, and for some months afterwards was engaged on surveys for extensions of the same line, and in assisting his father at Bilbao in similar work for the Somorostro Iron Ore Company. Visiting England for a holiday he was prevented from going back to Spain by the Carlist War. He was then for a short time in the office of Mr. G. B. Bruce, Vice-President Inst. C.E., assisting in the preparation of working drawings for New Zealand and Spanish railways. In April 1875 he was nominated by Sir Charles Hutton Gregory, K.C.M.G., Past-President Inst. C.E., to the Ceylon Government Railway extension survey-staff, which service he resigned in 1877, to undertake private surveying in the Colony, in conjunction with Mr. Walter F. Garland, Assoc. M. Inst. C.E. (now Commissioner of Public Works in Johore). During this period, namely, on the 5th of December, 1876, he was elected an Associate Member of the Institution. In 1878 Mr. Mayes proceeded to Johore to work for the Maharajah. In 1882 he obtained an appointment on the New South Wales Government railway extensions, and had charge of works as Resident Engineer at Tenterfield for rather more than two years. He died at Sydney on the 27th of October, 1884, from phthisis, originating in a chill taken when he was very weak. He had been suffering from chronic diarrhœa for more than a year, the climate of the district where he was stationed being very unfavourable for such a complaint. He was always ready to make the best of things under the difficulties inseparable from the nature of his work in uncivilized countries, was a steady, accurate and reliable assistant-engineer, and a beautiful draughtsman.

ARTHUR SULIVAN, the second son of Colonel Sulivan (late 5th Royal Irish Lancers), was born at Bath on the 28th of April, 1852. He was educated first at Shrewsbury, and then entered the Royal Indian Engineering College at Cooper's Hill, where, after being first in the two previous years' examinations, he came out first also in the final examination in 1876, and in consequence of his attainments was made a Fellow. He joined the Public Works Department of India in October 1876, and was placed in charge of exceptionally heavy works for a junior assistant on the Holkar and Neemuch (State) Railway. The Sewbridge of eleven spans of 100 feet, the Simli of nine spans of 40 feet, a large number of minor works, the platelaying, train-management, and quarries, were all directly under him, and his services were several times the subject of special recommendation to the Government of India.

In October 1881 Mr. Sulivan resigned his appointment, and took a contract for the erection of the ironwork on the Neemuch-Nusseerabad (State) Railway. In spite of several delays, he completed in five months thirty-one spans of 100 feet bridge-girders, and six spans of 60 feet. On his return to India in October 1882, he undertook the metalling and consolidating of 36 miles of the Ujjain and Agar Road, in Central India, which occupied ten months. Having perfected a clever design for iron staging for rapid girder-erection, he completed in six and a half months thirty-five spans of 150-feet girders, twenty spans of 100-feet girders (weight aggregating 5,700 tons) on the Southern Mahratta Railway; at the same time, in May and June he finished the Sipra bridge at Ujjain, six spans of 150 feet. In January 1885 he commenced the erection of the ironwork of the Sind-Pishin (State) Railway. The difficulties he met with from unusually heavy floods and the climate were terrible, and the work was closed by Government on account of a violent outbreak of cholera in June. Mr. Sulivan was on his way home, when he died on the 5th of July, 1885, of fever, brought on by overwork and exposure, at the early age of thirty-three.

He was a clever mathematician, a man of marked ability in every way, and possessed of great energy and capacity for carrying out work; while his love for the profession made him most zealous and conscientious in the performance of all he undertook, at the same time that his kindness and tact won him the esteem of both friends and employees. He was elected an Associate Member of the Institution on the 4th of February, 1879, having previously been a Student.

BENJAMIN WARNES THURSTON was born in 1816, at Brooke, in Norfolk, and was educated at Norwich, after which he acted for upwards of thirteen years as Sub-manager, &c., at the gasworks in that city, for the British Gaslight Company, and there acquired a knowledge of gas-manufacture and gas-engineering. In 1846 he accepted an appointment as Resident Engineer to superintend the completion of the construction of the Hamburg Gasworks, which post he filled with great advantage both to the contractors and to the Company, who were much troubled owing to the works being on an island in the River Elbe liable to overflows. The whole of the immense buildings and gas-holders rest on piles driven to a great depth through peat and sand. The difficulty of his task was increased by the German workmen in those days being little skilled in engineering, as well as by the intense frosts and inundations to which the Elbe was subject. Mr. Thurston, however, overcame all obstacles by his remarkable force of character and ability, which led to his being appointed sole Engineer and Manager to the Hamburg Gas-Company, positions he held until 1874, when the thirty years' concession to the Company expired, and the works became the property of the State of Hamburg. During the twenty-nine years he held these offices, large additions were made to the works. The financial results of his administration were dividends which ultimately reached 66 per cent. per annum.

Mr. Thurston was much consulted by other Gas-Companies on the continent, and was employed to design and construct gasworks for many towns in Germany, Finland, and Poland. He was also Engineering Director of several gasworks. He invented improvements in apparatus for gas-purification, and in furnaces for utilizing coal-tar as a fuel for carbonizing coal, both of which were extensively adopted on the continent. He was one of the first to use hydraulic cranes for unloading steam-colliers. He continued to practise as a Consulting Engineer until the end of 1875, when he retired after forty-three years' hard work, and lived at Eimsbüttel, a suburb of Hamburg.

Mr. Thurston died on the 26th of May, 1885, leaving a widow and grown-up family to lament his loss. He was elected an Associate of the Institution on the 3rd of April, 1857. In writing to the Secretary in 1878, he expressed regret that circumstances had prevented his being an active member, owing to his numerous engagements on the continent, which occupied all his time, and required his undivided attention.

Mr. Thurston's mental characteristics were very marked. He possessed great energy and perseverance, a powerful memory, natural constructive ability, and a facility for thoroughly and clearly thinking out the consequences of any course of action he might have under his consideration. His upright character and kindness of heart won for him a large circle of friends.

CHARLES FREWER was elected an Associate of the Institution, on the 2nd of February, 1866. He was at that time Manager, in London, of the Governor and Company of Copper Miners in England, a coal, copper, iron, and tinplate Company, which has been extinct for some years, but was then holding a Royal Charter granted as early as the year 1691. First as Secretary, and subsequently as Manager and Secretary, his engagement with this Company extended over a period of twenty-one years, and to within a short period of its dissolution, so that the energies of his comparatively short life may be said to have been principally expended in this Company's service. In 1873 he commenced trading on his own account as a railway-iron and general metal-merchant and agent, and he continued this business until his death. Although particularly unobtrusive, he had during his career come in contact with a large number of business men directly and indirectly interested in the iron trade, including not a few members of the engineering profession, and he secured their confidence and respect, and in many cases their friendship, by his unremitting attention to the business entrusted to him, and by his strict and unswerving integrity. He took great interest in the proceedings of this Institution, attended its meetings regularly, and for many years officiated as one of the Scrutineers at the Annual Election of its Council. He was also elected to the Auditorship of the Institution for the years 1875 and 1876. He was exceptionally proficient in matters of account and in secretarial work, and among several appointments of a kindred nature, which he held at the date of his decease, was that of Auditor of the South Indian Railway Company, an office he had filled for five years. In his earlier private life, and even later on, when he had the responsibilities of a large family resting upon him, he devoted a considerable portion of the time which he had at his disposal to benefit his less-favoured fellow-man at home and abroad; and, as instancing his liberality of heart, it may be recorded that from the first he unfailingly devoted to charitable objects 10 per cent. of his earnings. Until within three months of his death he had enjoyed complete immunity from serious illness. Symptoms of blood-poisoning, contracted quite unconsciously, then showed themselves, and he died of intermittent fever on the 15th of July, 1885, aged 57 years.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Experiments on the Strength of Ice. By A. FRÜHLING.

(Zeitschrift des Vereines deutscher Ingenieure, May 9, 1885, p. 357.)

Tensile strength.—The experiments on the tensile strength were made with an ordinary cement-testing machine, the testing pieces being frozen in a metal mould approximating to the section of a double-headed rail. Nine such pieces of 5 square centimetres (0·77 square inch) cross-section were tested at a temperature of 23° Fahrenheit, and gave the following breaking weights—

10·0 kilograms per square centimetre (142·2 lbs. per square inch).
13·0 „ „
12·5 „ „
15·5 „ „
14·5 „ „
14·2 „ „
15·7 „ „
12·6 „ „
11·4 „ „

giving a mean of 189 lbs. per square inch.

It is to be noted that the ice-blocks did not always break where the cross-section was smallest, perhaps because as the load was increased they began to slip in the hook-shaped jaws of the apparatus and had to be held rather sideways.

Strength to resist Compression.—Five rectangular test pieces were sawn out of clear block ice, and loaded at a temperature of 23° Fahrenheit, until they began to crack in the centre, which took place at the pressures given in the 4th column of the Table. As the pressure was increased the cracks became more numerous until they went all through the test piece. As the pressure was further increased the height of the blocks began to diminish and their cross-section to increase until ultimately they were flattened out, never, however, giving way suddenly. The only stage in the flattening out at which the pressure was accurately noted was that at which the height of the block began to diminish. This is given in the last column of the Table:—

Dimensions of Test-Piece.			Pressure at which Cracks appeared.	Pressure at which Height began to diminish.
Sides.	Cross-Section.	Height.		
Millimetres.	Millimetres.	Millimetres.	Kilograms per Square Centimetre.	Kilograms per Square Centimetre.
75 (2·95 inches.)	70 (2·76 inches.)	65 (2·55 inches.)	4·28 (60·8 lbs. per square inch.)	15·24 (216·8 lbs. per square inch.)
63	53	56	12·89	24·00
58·5	57	50	9·89	27·26
58	57	60	14·40	24·20
55	56	60	10·70	17·04

Strength to resist Bending.—Pieces of ice sawn out of the block, and varying in length from 24·8 to 42·9 inches and of rectangular cross-section were supported at each end and loaded till they broke, the deflection being measured at intervals. Experiments I. to IV. were made during a thaw, at a temperature of from 34° to 39° Fahrenheit. Experiments V. to IX. were made at a temperature of from 28½° to 30½° Fahrenheit:—

No. of Test.	Length of Test-piece.	Distance between Supports.	Depth.	Breadth.	Weight of Test-piece between Supports.	Load at Centre.	Bending Strength.
	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Kilograms.	Kilograms.	Kilograms per sq. centimetre.
I.	1,090 (42·9 ins.)	746 (29·4 ins.)	46·5 (1·83 in.)	82 (3·23 ins.)	2·50 (5·5 lbs.)	11·3 (24·9 lbs.)	7·7 (131·5 lbs. per sq. inch)
II.	1,030	746	58·0	96·0	3·84	25·0	9·4
III.	1,050	746	42·0	110·0	3·07	14·0	9·0
IV.	680	600	48·0	70·0	1·63	12·0	7·1
V.	680	500	43·5	100·0	1·91	30·0	12·0
VI.	680	600	38·0	52·5	1·20	23·5	28·0
VII.	760	650	49·0	60·5	1·50	16·0	11·1
VIII.	760	680	51·5	71·0	2·05	24·5	13·8
IX.	760	660	39·0	96·0	2·00	24·0	16·5

The results show that the strength to resist bending is decidedly greater below freezing point.

The value of the modulus of elasticity (E) is calculated from the results of these experiments with very widely varying results, which the Author accounts for by differences in the nature of the ice, in the various bars, and by the difficulty in ascertaining when the limit of elasticity had been exceeded in applying the gradually increasing weight. In Experiments I. to IV. (above freezing point) the value of E varies from 4,300 to 12,600, and in Experiments V. to IX. (below freezing point) from 8,560 to 25,600 kilograms per square centimetre.

W. B. W.

Strength of White Pine, Bricks, and Stone.

By Prof. W. A. Pike.

(Journal of the Association of Engineering Societies, August 1885, p. 363.)

The Author gives the results of tests recently made in the testing laboratory of the University of Minnesota. Sticks of thoroughly seasoned white pine were tested for tensile strength. They were dressed to a uniform scantling 12 inches in length, with shoulders on the ends to take the pull. In scantling they varied from $\frac{3}{4}$-inch square to $1\frac{3}{8}$ inch by $2\frac{1}{2}$ inches; average specific gravity, 0·66. The average ultimate tensile strength was 7,373 pounds per square inch. It was observed that the longitudinal shearing strength of the ends of the sticks, in resisting the pull, was less than has been generally given. The ends had a shearing-area of 45 square inches; but it was necessary to spike and clamp the ends in order to prevent splitting. Thirty-five tests were made of white pinewood for resistance to compression, in which the pieces varied from 1 inch cubes to pieces 3 inches square and 54 inches in length. Of those which broke by direct compression, the crushing resistance averaged 5,283 pounds per square inch. One-inch cubes bore 7,800 pounds. Pieces 3 inches square and 54 inches long bore 5,222 pounds per square inch; 24 inches long, 5,038 pounds; and 12 inches long, 5,505 pounds per square inch. Of those which failed by a combination of crushing and bending, from 54 inches to 24 inches long, and from 4 by 2 inches to 2 by 1 inch in return, the average actual stress or load was about 3,000 pounds. The Author argues from the results that the value of the usual constant in the ordinary formula for the resistance of struts is much too great.

Half bricks, placed between pieces of paste-board, were tested for crushing resistance. St. Louis bricks failed flat-wise under 6,417 pounds per square inch; edge-wise, under 4,080 pounds. Hastings red brick, hard, medium, and soft, failed respectively under 2,017 pounds, 2,012 pounds, and 1,748 pounds per square inch. With reference to position in the kiln, Little Falls bricks varied from 3,467 pounds to 980 pounds per square inch, in crushing resistance.

The results of several tests of stones, including sandstone and limestone, are added.

D. K. C.

On the Behaviour of Cast-iron, Wrought-iron, and Stone Columns in Fire, and under rapid Cooling (by Water).

By J. Bauschinger.

(Mittheilungen aus dem mechanisch-Technischen Laboratorium der k. Technischen Hochschule in München, No. 12, 1885, p. 1.)

In 1884 new regulations were issued by the Berlin police authorities with regard to the use of cast-iron columns in new buildings, or alterations of old ones. According to these, "cast-iron columns which are not protected from the direct action of fire may no longer be employed under the main walls of buildings of which the lower floors are used for business and storage purposes, and the upper floors as dwellings. In place of them will be allowed: (*a*) wrought-iron columns; (*b*) cast-iron columns, which are surrounded by an irremovable casing of wrought iron insulated by an air-space from the column; (*c*) columns of stone set in cement."

The severe character of these regulations induced the Author, at the instigation of Mr. Kusterman (the owner of a large foundry in Munich) to undertake a series of experiments in order to ascertain with accuracy the behaviour of columns of various materials, but especially cast and wrought iron, under the action of fire and rapid cooling by water. The regulations in question were the outcome of observations made after a large fire at a manufactory in Berlin, on the condition of the cast-iron columns used in its construction.

The Author's experiments were made on columns of cast-iron, wrought-iron, and building materials of various kinds. The column to be tested was subjected, in the Werder testing-machine, to the compressive load it would have to sustain in actual use, and in this condition heated to the desired temperature, and then suddenly cooled by jets of water.

For the purpose of heating, the column tested was partially surrounded by a perforated wrought-iron trough, in which wood was burned. Owing to the nature of the arrangements, cooling could only be effected from the upper side, the position of the column being horizontal, but this corresponds with what actually occurs at a fire in the majority of cases. An arrangement for measuring the deflections of the column during the experiments, in two directions at right angles to each other, was made by means of wires attached to the former, and acting on index fingers placed at a convenient distance.

The temperature of the material tested was measured by means of alloys having various melting points, the highest being 600° Centigrade.

Six cast-iron, three wrought-iron columns, and fifteen of various building materials were tested.

The results showed that cast-iron columns best withstood the action of the fire and water, continuing to support their load even when red-hot and already cracked in places, whereas wrought-iron columns collapsed entirely under similar conditions.

The building materials tested were granite, marble, tuff, dolomitic limestone, concrete, paving-stone, granitic marble, various kinds of sandstone, and ordinary bricks. Of all these materials the concrete proved to be the best, and after this ordinary brickwork. The concrete column tested remained uninjured after exposure to the treatment for one hour and three-quarters. None of the natural building-stones resisted the fire; granite was relatively the best, then tuff.

The columns used were of sections and lengths occurring in practice; many were subjected several times to the treatment described.

The Paper is accompanied by illustrations showing the injuries sustained by the different columns.

G. R. B.

Moving a Chimney.

(American Architect, July, 1885.)

One of the most difficult transfers of heavy structures yet attempted was successfully completed in Salem, Massachusetts, a few weeks ago. A brick factory-chimney, 90 feet high, and only 6½ feet in diameter at the base, was moved, with the aid of six men and two horses, 100 feet, and safely deposited upon a new foundation. The chimney was nearly cylindrical, the upper diameter being 5 feet, and it was estimated that a sway of 3 inches from the vertical would bring it to the ground, so that great precautions were taken to prevent lateral movement in transferring it to the platform on which it was to be transported.

A cage was first built around the chimney, consisting of horizontal timbers supporting shores, which extended twenty-three feet up the sides of the shaft, and were reinforced by a second set of shorter ones beneath. After these were in place, and well secured, holes were cut through the brickwork, and needles inserted, under which thirty-four jack-screws were placed, and the shoring and shaft raised together high enough to allow a rough platform to be set in place. The platform, which was of strong plank, extended to the new position of the chimney, and by levelling it carefully, and employing a large number of rollers, the load, weighing 130 tons, was easily moved into place.

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Bridge over the Indus at Sukkur.

By F. E. Robertson, Assoc. M. Inst. C.E.

(Professional Papers on Indian Engineering. Third Series, vol. iii., No. 10, p. 21, 2 plates.)

The Indus Valley railway is designed to cross the River Indus at Sukkur, where its bed passes through limestone rock, and is divided into two channels by Bukkur Island. The Rohri channel is to be crossed by a cantilever bridge, with a single span of 820 feet, in course of construction. The bridge over the Sukkur channel has been completed. It consists of three spans of 278, 238, and 94½ feet respectively; and steel semi-parabolic girders, 28 feet deep at the centre, and 12½ feet at the ends, carry the bridge over the two larger spans. Accommodation is provided between the girders for a single line of rails and a cart road, whilst a footway, 5 feet wide, is supported, outside the girders on each side, by cantilevers. The river pier between the two large spans had to be built in a depth of 9 feet below the low-water stage of the river, running with a velocity of about 6 miles an hour. A cofferdam was formed by securing rails in holes made in the rock, about 6 to 8 feet apart, to which walings were fastened, and sheet piles driven down between. The inner wall of the dam was formed of mould-boards, 9 inches thick and 9 feet square, secured to staging above; and the intervening space of about 5 feet was filled with 2 feet of concrete at the bottom and "gutch" above, after the bottom had been carefully cleaned by divers. This cofferdam proved perfectly watertight, and no blasting was needed; but the construction of the second river-pier was more difficult, owing to the irregularity of the rock at that site.

The staging from the Attock bridge, which had been completed, was utilized for the erection of this bridge. Wrought-iron cylinders, 3 feet in diameter, were employed for supporting the trusses for the erection of the middle and smaller spans, for the river there had a depth of 25 feet in flood time, and a velocity of 13 feet per second. There is a chasm, 70 feet deep at low water, in the centre of the largest opening, and the velocity of the current is never less than 6 miles an hour; so supports had to be erected on each side of this chasm for carrying the staging over it. Two old bridge boats, lashed together and connected by timbers, filled and surrounded by rubble stone, formed the foundation on each side for the supports and the raking struts, which, with central trusses, carried the staging across the gap. The staging, which was erected in a month, proved perfectly rigid, but the foundations settled 2½ inches before the erection of the girders was commenced. The girders were given an extra camber to allow for sinking, but as their erection only occupied five days, no perceptible sinking took place till they were closed. A sudden flood, 6 feet high, occurred during the riveting of the main girders, but they were bolted and the flooring put in rapidly, so that when the staging settled the bridge bore its own weight of 530 tons. The cost of the two cofferdams was 16,385 rupees, and the cost of labour in the erection of the ironwork of the bridge was 43,549 rupees.

L. V. H.

The Olona Viaduct. By Luigi Trevellini, Engineer.

(Annuario scientifico ed industriale, Milan, 1885, p. 466.)

Amongst the most important works constructed of iron in Italy during 1884, is that which carries the new railway from Varese to Como across the Olona, at a height of about 60 metres (196·8 feet) above the bed of the torrent. It was executed by the "Impresa Industriale" of Naples under the direction of their engineer Mr. Cottrau. The principal novelty in this viaduct, is the substitution of wrought- for cast-iron in the columns of the piers, which are light and of elegant design. They consist of four wrought-iron columns, 35 centimetres (13·78 inches) in diameter, connected together by horizontal and vertical bracings.

The total length of this viaduct is 235 metres (770·8 feet), the central span is 67·6 metres (221·73 feet), and is carried by two piers about 51 metres (167·28 feet) high. The weight of the superstructure is 2,163 kilograms per lineal metre (1452·58 lbs. per foot) whilst that of the iron piers is 2,332 kilograms per metre (1566·07 lbs. per foot). The iron girders, which were made at the company's works at Savona and Castellamare, were erected on the one bank of the Olona, and launched across the valley in a single operation without the use of temporary supports.

P. L. N. F.

Stranover Viaduct. Changing of the Ironwork.

By Franz Prasil.

(Zeitschrift des österreichischen Ingenieur- und Architekten Vereins, 1885, p. 21.)

When the Turnau-Kralup-Prague railway was amalgamated with the Bohemian Nordbahn, the bridges on the Schifkorn system between Turnau and Kralup, over which the engines of the latter line had to run, were found to be too weak, and it was decided to replace them by riveted-framed structures. The Stranover Viaduct is one of these. It is on the line from Neratowitz to Jungbunzlau, and crosses the Stranover valley at a height of about 100 feet. It consists of three openings of 123·4 feet clear span, crossing two public roads and two unimportant watercourses. The original ironwork consisted of three single-line bridges on the Schifkorn system, with the roadway carried at the middle height of the trusses. The changing was done on a new system. The whole of the ironwork (two main girders, cross-bearers, and bracing) for one span was completed, resting on two eight-wheel trollies in a siding adjoining the viaduct. It was then run out into its position on the bridge, and supported from the piers on cast-iron jointed columns. The trollies were then removed, and the old bridge was attached to, and hung from, the new one. A scaffolding was also hung from the new bridge, on which the men worked, to remove the old bridge. The new bridge was then lowered to its permanent bearing on the piers.

The new construction consists of two main-braced girders, 128·6 feet span, 14·2 feet deep, and 9·8 feet apart centre to centre. The permanent-way is carried on the top, the under side of the rails being 5·8 feet above the bearing of the girders. The rails rest on cross-sleepers, carried by iron longitudinals 5·9 feet apart. These are supported by cross-girders about 12·8 feet apart. Between these is the horizontal wind-bracing. When the ironwork for one space was completed, and the permanent-way fixed upon it, it was supported at the second cross-girder from each, and upon two eight-wheeled bogies, and run from the siding where it had been erected on to the old bridge, until it was exactly over the place it was to be lowered into. The height of the bogies was so arranged that the under side of the new girders was 2 inches above the level of the rails, and the bogies, with their load, were in stable equilibrium with a wind-pressure of 31 lbs. per square foot.

Each head of the new bridge was then supported at the piers by four cast-iron columns, two directly under the vertical ends of the main girders, and the other two under the last cross-girder, at the points where the longitudinal rail-bearers are attached. These columns consisted of short lengths 10 inches in diameter, with outside flanges, through which they were bolted together by eight bolts. The outer and inner column in each case were firmly connected by plates, and the two inner ones by movable timber cross-bracing. The bottom length of each of these columns was conical, and fitted on to a screw-jack, by means of which the bridge could be raised or lowered.

When these columns had been adjusted the bridge was raised slightly, the bogies withdrawn, the permanent-way of the old bridge removed, and the new bridge lowered until it almost touched the forty-one remaining cross-bearers of the old bridge; to these it was firmly attached, and the old bridge was thus hung from the new one. At this period of the work the eight columns had to bear their maximum load, which was made up as follows:—

	Tons.
New bridge and permanent way	71·4
Two trestles and parts of bogies	5·1
Old bridge with planking, but without permanent way	76·7
Hanging scaffolding	7·1
Men and tools	3·9
Total	174·2

which gives a pressure of about 2·2 tons per square inch upon the cross-section of the column.

The old bridge was now gradually removed, leaving the new bridge supported on the eight columns, at a height of 14·1 feet above its permanent level. To this it was gradually lowered by means of the eight screw-jacks and jointed columns, a length being removed from two of the columns at a time, the half weight of the structure during the operation being supported upon the other two columns at that pier.

The work of changing the bridges was carried out on July 20th, August 17th, and September 1st, 1884, and commenced at 9.15 P.M.

The time occupied in the work was as follows:—

——	Estimate.		First Span.		Third Span.		Middle Span.	
	h.	m.	h.	m.	h.	m.	h.	m.
Bringing the new bridge into position.	..	30	..	45	..	20	..	15
Fixing and bracing the eight columns.	1	30	2	..	1	20	..	55
Removing the trollies and attaching the old bridge	2	30	4	30	4	..	2	10
Removing the old bridge	10	..	8	..	6	30	4	..
Lowering new bridge, removing working platform, and making good permanent-way	8	30	16	..	13	..	7	15
Total	23	..	31	15	25	10	14	35
Intervals of rest	..	..	7	30	1	30	1	15
	..	..	38	45	26	40	15	50

Eighty men were employed in the work.

The Paper is illustrated in detail.

W. B. W.

Rail-testing in Russia. By N. Belelubsky.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereines, June 6, 1885, p. 223.)

Since 1878 the Russian Ministry of Ways and Communications has enforced the following conditions for the testing of iron and steel rails.

The whole supply of rails is first to be inspected and their dimensions checked. After the removal of defective rails the rest are to be piled in stacks of 1,000 rails each. From each of these stacks the Goverment inspector is to choose three rails, from each of which three test pieces 6 feet in length are to be carefully cut.

Of the three test pieces one is to be subjected to a pressure test and the other two to a striking test. If the testing takes place at a higher temperature than from 0° to 10° Fahrenheit, two at least of the pieces must undergo the striking test reduced to that temperature. The cooling is done by surrounding the rail in a wooden box, 9 feet 4 inches by 3 feet by 2 feet, with a mixture of ice and salt. The temperature of the rail is measured by a thermometer, placed in a hole bored in the end of the rail and filled with mercury.

1. *Test for Bending under Load.*—The piece to be tested is laid on supports 3 feet 6 inches apart, and subjected for five minutes to the application in the middle of the load A (see Table), when the deflection must be not less than 0·12 inch (3 millimetres) on removal of the load, but the permanent set not more than 0·08 inch (2 millimetres). The weight is to be applied twice, and after the second application the permanent set must not exceed 0·08 inch.

2. *Bending test with increased Load.*—Pieces which have stood the first test are to be subjected to the load B (see Table), which they must support for five minutes without breaking.

3. *Test by falling weight.*—The remaining two pieces of the same rails are to be placed on the supports, and after two strokes from a weight of 923·7 lbs. falling from a height H (see Table), must not show any external signs of fracture.

4. *Test of the goodness of the material.*—All pieces which have stood the above tests are put under the same hammer, falling from H + 1, H + 2, &c. feet until they break.

Note.—The testing apparatus is made to a normal pattern, and the site for its erection is chosen by the inspector. The metal base must weigh not less than 19·7 tons, and the bottom of the stone foundations must be not less than 4 feet 6 inches below the surface of the ground.

The following Table gives the values of A, B, and H, referred to above, for various weights of normal steel and iron rails :—

——	Weight per yard.	Load A.	Load B.	Height H.
	Lbs.	Tons.	Tons.	Feet.
Steel	46·4	9·00	13·92	4·75
	50·4	11·06	16·38	5·65
	54·4	13·10	19·66	6·50
	58·5	15·15	22·52	7·50
	64·5	17·20	25·39	8·50
Wrought iron . .	54·4	9·00	11·47	4·00
	54·4	11·06	13·51	4·55
	64·5	13·10	16·38	5·25
	70·6	15·15	20·07	6·00

If more than a third of the pieces do not not stand the tests all the thousand rails from which they have been taken are rejected, but if a third, or less than a third fail, it is permitted to redivide the stack of one thousand into lots of two hundred to three hundred, and make the acceptance of these depend upon the tests of at least two rails from each stack.

The putting aside of large quantities of steel rails from year to year, in consequence of breakage or wearing out, suggested to the Imperial Russian Technical Society in St. Petersburg to contribute, by examination of the removed rails, to the discovery of the causes which influence the life of rails; and especially with a view to finding whether the present testing regulations require alteration, and whether harder or softer material is to be preferred for rails. To forward these investigations nearly all the Russian railways sent to the Technical Society a large number of samples of rails and tires, with statistical notes referring to each. Although these investigations were commenced by the Technical Society as a private undertaking (with, however, the support of the railway management), the work received official recognition in 1884 from the Ministry of Ways and Communications, and the convention of representatives of steel-works and of railway managers called together by this Ministry decided to defer until the conclusion of the first series of investigations the answering of the question whether the regulations for testing and accepting rails which have been in force for the last seven years required to be altered or not? This first series consists in the examination of worn rails and tires. The results will be put together in the graphic form, and will probably be ready by January 1886. A further series of investigations is planned, in which steel rails of different degrees of hardness, furnished by Russian steel works, will be laid in and periodically inspected by the commission.

The following are the alterations in the regulations for the acceptance of rails suggested by the Management of the State Railways in conjunction with the Commission of the Imperial Technical Society.

1. In the bending test with load A the maximum permanent set shall be 0·04 inch (1 millimetre), instead of 0·08 inch (2 millimetres), and no demand need be made as to elasticity.
2. The test for bending with increased load B may be omitted.
3. If the temperature of the air is below 9·5° Fahrenheit, no artificial cooling need be applied.

The following is the programme of the investigation now going on:—

A. Data to be collected by the railway management: (*a.*) Type of rail, name of works, mark and year, original weight per running foot. (*b.*) Load on the axles of engines running upon the line. Gross tonnage passing over the rails. (*c.*) Weight of rail when taken up. Cause of failure: broken (time, place, on or between the cross-sleepers); not broken but worn out. (*d.*) Position of the rail in the line: in straight or on curve (radius, inner or outer line), level or on gradient, quality of ground and ballast. (*e.*) Life of rail.

B. Ministerial tests: Striking and bending, carried out by the Commission at the Putiloff works (St. Petersburg). (*a.*) Bending test: loading in press; deflection permanent and temporary. (*b.*) Striking test: Temperature of the tested rail; height of fall of the monkey (1½ ton in weight). Deflection at first and second blow.

C. Tearing test, carried out in the mechanical laboratory of the Road-Construction Engineers Institution. (*a.*) Tensile strength (R), relative extension (*i*), contraction (*c*) at fracture. Product R*i* and sum R + *c*.

D. Torsion test, carried out at same place as C. Limit of elasticity, shearing strength, work at limit of elasticity and at fracture.

E. Quantitative analysis, carried out in the chemical laboratory of the Finance Minister. Percentage of Carbon, Manganese, Silicon, Phosphorus, Sulphur.

Graphic representations of the results will be drawn up.

W. B. W.

Apparatus for Washing Rails.

(Giornale del Genio Civile, 1885, p. 195.)

The Swiss Central Railway Company make use of hot water, issuing at a high pressure, for washing the rails in the Hauenstein tunnel, which is about 1½ mile long, and is a straight line on a gradient of 28·2 per 1000. In the first instance a low pressure was tried, but the adhesion diminished instead of increasing, and high pressure was then adopted. A small ejector is placed upon the footplate; this is actuated by steam from the boiler, which forces the water (drawn from the tender-tank) along a 1-inch pipe to the front of the engine. The pipe is then divided into two branches, which discharge the water, by orifices ⅛ inch in diameter, at a temperature of 140° Fahrenheit, and a velocity of 92 feet per second, at points about 2½ inches above the rails, a little in advance of the wheels. The consumption of water is about 11 gallons per minute. The effect is that the rails are thoroughly cleansed, and slipping of wheels, which was constantly occurring in this tunnel before the system was adopted, now very rarely takes place. Sand is seldom required, and the wear of the rails and tires is greatly diminished. The company has now fitted the apparatus to all the six-wheel coupled tender engines, which work both the passenger and goods trains through the tunnel. The engines are still fitted with sand-boxes, sand being used in the open.

W. H. T.

The Expense of Railway Transport.

By Lieut.-Col. T. F. Dowden, R.E., Assoc. Inst. C.E.

(Professional Papers on Indian Engineering. Third Series, vol. iii., No. 10, p. 1.)

The system of special rates for freight on railways, so common in England, does not exist in India. The through rates in India are generally the sum of the local rates for each line, and these have to be so fixed as to afford a fair profit at all times. In two previous Papers, the effects of the speed of trains and of delays in working were considered,[1] whilst the present Paper treats of the economical effect of working as a whole. In 1883 there were 10,563 miles of railway open in India; their working expenses averaged 204 rupees per day, and an average of 10·4 trains per day ran over every mile open, and the average cost accordingly was 196 rupees a train-mile. This, however, is merely an average, and does not give the cost of carriage in any particular case. The cost varies with the gauge of the railway, the gradients, the size of the engines, the amount of traffic, and the speed travelled. Railway working-expenses may be divided into material and time charges, and the former vary, after a certain point of speed, as the speed, and the latter vary inversely as the speed; and these charges approximate to an equality when the railway is working most economically. The decrease in cost per train-mile, as the number of trains increases, is large at first, but appears to approach a limit with twenty trains per day. The economy also effected by increasing the length of the trains is limited to about thirty vehicles, in the case of a given engine drawing a train up an incline of 1 in 300, at 20 miles an hour. There appears to be no advantage in increasing the load of a train, as long as there is room on the line for twenty trains per day, but beyond this point the weight of the train may be advantageously increased. If, however, this cannot be done for constructive reasons, the line may be doubled; but the saving with forty trains, in place of twenty, is small compared with the extension of traffic. The speed, however, on a double line is about double that on a single line. A speed of 29 miles an hour gives the greatest train- and line-capacity under the specified conditions. Steep gradients limit the capacity of goods trains, for their weight should not exceed what the engine can draw up the steepest incline at 10 miles an hour. The stations have also to be increased, and the through speed is reduced where the gradients are long and steep. The dividend depends on the number of units of traffic carried at a profit as compared with the capital cost, and is necessarily greatest for a given unit of profit when the railway is fully utilized, though the capital cost is somewhat increased in proportion to the increased traffic. The cost of the sleepers and ballast, the rails, the rolling-stock, and the stations, being each represented by 1; the cost of the works up to formation-level may amount to a sum represented by from 1 to 4, according to the country traversed. The cost of the latter works is not much affected by the gauge, whereas the former groups would need an increase of 50 per cent. for broad gauge in place of narrow. A large capacity for traffic, though not materially reducing the working expenses when it reaches twenty trains per day for a single line, by increasing the units of profit, increases the interest on the capital. The suitable rates for freight, as gathered from the tables representing the working expenses per train-mile, and interest on capital at 4 per cent., are as follows:—

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[1] "Tables for Calculating Speed of Trains with various Loads," Professional Papers on Indian Engineering, vol. ii., p. 189. "Running- and Through-Speeds on Railways," *ibid.*, vol. iii., p. 1.

SINGLE LINE.

Easy country: 6·6 trains daily.

	Rupees.
Working expenses	2·340
Interest	0·700
Total	3·040

Easy country: 20 trains daily.

	Rupees.
Working expenses	1·810
Interest	0·330
Total	2·140

Heavy country: 6·6 trains daily.

	Rupees.
Working expenses	2·340
Interest	1·370
Total	3·710

Heavy country: 20 trains daily.

	Rupees.
Working expenses	1·810
Interest	0·550
Total	2·360

DOUBLE LINE.

Easy country: 80 trains daily.

	Rupees.
Working expenses	1·520
Interest	0·135
Total	1·655

Heavy country: 80 trains daily.

	Rupees.
Working expenses	1·520
Interest	0·196
Total	1·716

Comparing a broad- and a narrow-gauge railway somewhat similarly situated, such as the Great Indian Peninsula and the Rajputana-Malwa Railway, with gauges of 5½ feet and 3¼ feet respectively, it appears that the working expenses per mile open and per train-mile are less for the narrow gauge; but measured by the ton-mile, the standard unit of freight, this unit on the narrow gauge costs more, owing to the smaller capacity per train, whilst certain of the charges for working trains are approximately constant, whatever their size. The relative economy of narrow- and broad-gauge railways depends on a balance between the cost of working expenses and interest on the capital expenditure. It appears that it is cheaper to adopt a 5½ feet gauge for four trains a day, than a 3¼ feet gauge with eight trains, when the difference in capital cost does not exceed £1,500 per mile; whereas with a traffic sufficient for only two broad-gauge trains, a narrow gauge would be cheaper, unless the difference in capital cost was only £250. The broad gauge is best suited for a heavy country. A comparison of a double line of 3½ feet gauge, with a single line of 5½ feet, gives the following results:—

Easy Country.	Capital Cost.	Capacity.	Interest per Train-mile at 4 per cent.	Working Expenses per Train-mile.	Total per Train-mile.
	£.	Trains.	Rupees.	Rupees.	Rupees.
Double line 3½-feet gauge .	9,798	80	0·135	1·16	1·295
Single line 5½-feet gauge .	6,000	20	0·330	1·81	2·140

As the carrying capacity of the broad-gauge train is double that of the other, the freight charge per ton-mile is in the ratio of 1·07 to 1·295, or 21 per cent. more on the narrow than on the broad gauge, in spite of the gross carrying capacity of the narrow being double that of the broad. Comparing now double lines of both gauges with equal traffic, the results are:—

Easy Country.	Capital Cost.	Capacity (equal).	Interest per Train-Mile.	Working Expenses.	Total per Train-Mile.
	£.	Trains.	Rupees.	Rupees.	Rupees.
3½-feet gauge	9,798	80	0·135	1·16	1·295
5½-feet gauge	10,580	40	0·292	1·70	1·992
Heavy Country.					
3½-feet gauge	14,298	80	0·196	1·16	1·356
5½-feet gauge	15,500	40	0·462	1·70	2·162

The ratio per ton-mile is as 1·295 to 0·996, or as 1·30 to 1 in the first case; and as 1·356 to 1·081, or as 1·25 to 1 in the second case, showing an excess of cost with the 3½ feet gauge line of 30 per cent. where the country is easy, and of 25 per cent. in heavy country.

L. V. H.

On the Cost of Transport on the Prussian State Railways in 1883–84. By E. Schemmann.

(Stahl und Eisen, vol. v., p. 519.)

The figures contained in this paper are in continuation of former reports upon the same subject, and are of additional interest as showing a marked diminution in goods traffic during the period under review as compared with former years.

The comparative importance of the goods traffic, including cattle upon the different lines, is shown in the following Table. The sections are named after the headquarters of the management of each.

	Net ton-kilometre per kilometre of line worked. 1883–84.	1882–83.
1. Cologne, Rhenish right bank	942,075	878,479
2. Elberfeld	914,279	856,092
3. Hanover	714,952	697,770
4. Cologne, Rhenish left bank	618,204	633,515
5. Frankfurt on-Main	503,744	480,451
6. Berlin	442,654	604,624
7. Magdeburg	425,053	433,772
8. Erfurt	414,708	..
9. Bromberg	194,370	244,624
Mean	541,816	582,749

Or an average diminution of about 7¼ per cent. The total traffic classified according to the different elements was:—

	Ton-kilometres.
A. Goods traffic:—	
1. Goods and cattle nett loads	8,389,394,321
2. Goods and cattle trucks, tare	10,525,538,980
B. Passenger traffic:—	
3. Passengers and baggage, nett loads	319,624,514
4. Passenger carriage, tare	3,576,624,341
5. Baggage wagons, tare	1,124,990,685
6. Post-office carriages, gross weight	444,198,878

The gross totals of the above items were—

	Ton-kilometres.
In 1883–84	24,380,371,719
And 1882–83	21,488,657,348

The total expenditure, excluding payments for the use of the foreign lines and receipts from sale of old stores, was—

	£.
In 1883–84	14,536,381
„ 1882–83	11,839,453

The increased cost is partly attributed to the increased length of lines, worked, partly to increased pay to the staff; but more particularly to the large outlay upon renewals and increase in the rolling-stock, the expenditure upon the latter being:—

	1881–82.	1882–83.	1883–84.
Length of lines open	11,706	14,622	15,735 kilometres
	£. 185,638	£. 373,336	£. 881,768

The average cost of moving 1 ton gross 1 kilometre was for all the lines 0·1532*d.* in 1883–84, and 0·1324*d.* in 1882–83.

But as the ratio of gross to paying load was 1 : 2·255; the cost per nett ton moved was 0·345*d.* for loads of all kinds, passengers and goods included.

As far as can be done from the somewhat deficient data supplied in the official reports, the Author calculated the cost of the different services as follows:—

	£.	
The total outlay was	6,403,648	on passenger service.
” ” ” ”	8,132,733	” goods ”

	1883–84.	1882–83.
The corresponding averages are—	d.	d.
Per passenger-kilometre	0·397	0·382

The highest receipts per passenger-kilometre are: 0·452*d.* (Cologne, left bank); the lowest, 0·354*d.* (Berlin); and the average of all the districts, 0·418*d.* The cost of moving 1 ton nett per kilometre was on the average of all the lines 0·233*d.* in 1883–84, and 0·208*d.* in 1882–83.

In another form the cost of moving a 10-ton load a distance of 100 kilometres is given for the different districts as follows:—

	1883–84.			1882–83.		
	£.	s.	d.	£.	s.	d.
Cologne, right bank	0	14	10·2	0	13	5·4
Elberfeld	0	17	0	0	15	10·8
Hanover	0	17	1·8	0	15	10·0
Cologne, left bank	0	19	7·4	0	18	1·1
Frankfurt	0	19	2·0	0	18	4·4
Berlin	1	1	9·2	0	18	6·0
Magdeburg	1	4	3·7	1	1	11·2
Erfurt	1	4	10·7		..	
Bromberg	1	7	7·4	1	1	5·8
Mean	0	19	4·8	0	17	3·7

The unfavourable figures in the districts of Berlin and Bromberg are partly accounted for by the competition of water-carriage, the weather having been specially favourable for navigation during the year; and partly by the absence of grain traffic from Russia and the Eastern provinces. The return on the capital of the State lines was 4·86 per cent. as compared with 5·13 per cent. on the preceding year.

H. B.

On the Principal Methods adopted for Insuring the Safety of Trains upon Italian Railways.

(Giornale del Genio Civile, 1885, p. 3.)

The traffic upon the Italian lines is not sufficient to require the adoption of the block system.

Trains following one another upon the same line of rails.—As a general rule a ten-minutes interval is allowed between the departure of the trains. If the speed of the second train is greater than that of the first, this interval is increased to fifteen or twenty minutes. A slow train must wait in a siding for a quick train to pass it unless it can reach another passing station at least fifteen minutes before the quick train is due there. On some lines, however, a luggage-train is allowed to follow a passenger-train at an interval of five minutes; on other lines the ten-minutes interval applies to all trains. Trains, after leaving the station, are protected by signals for the prescribed times. Upon gradients of 25 per thousand or more no train is allowed to leave a station till informed by telegraph of the arrival of the preceding train at the next station. That these regulations are sufficient for ensuring safety may be seen from the fact that during the ten years 1873–82, there were on the Upper Italian Railways (which have the heaviest traffic in the kingdom,) only three collisions between following trains, all of which were caused by negligence. This corresponds to one collision per 55,000,000 train-kilometres. The average number of trains per day in the same direction upon this system is fifteen, and the maximum thirty-five.

Trains running in opposite directions upon a single line.—As a general rule these trains are run according to the time-tables without any special precautions. Notice of the departure of a train is telegraphed to the next station. If a train is more than a quarter of an hour late the fact is notified to all stations up to that at which it ought to have arrived. When a train is so late as to render necessary an alteration in the arrangements for passing another train travelling in the opposite direction, the alteration, after being determined, is telegraphed to the other stations affected by it, and acknowledged by them, and the station-master at each place is bound to sign a register kept for the purpose, in which the alteration is noted. The engine-drivers and guards of the trains receive and sign written orders in respect of the alteration. This being the system in use, the station signals, except when the traffic is heavy, stand, as a rule, at "line clear." The system has the defect that it depends for its working entirely upon the attention of the railway-servants. On some lines electric-bell signals have been adopted, and a description of several ways of working them is given in the Paper.

The Westinghouse and Smith-Hardy continuous brakes have been adopted to a small extent during the last five years, but no decision has yet been come to as to their respective merits.

Special precautions are taken to prevent accidents in tunnels; when these are short their two ends are protected by signalmen, and when long they are divided into lengths by signal-boxes inside the tunnels.

Bell-signals are used at level crossings where there is much traffic. There is a law that the gates are always to be closed five minutes before the arrival of a train, and when the gatekeeper has nothing but the time-table to guide him, if a train is late the gate has to be closed from five minutes before it is due till it has actually passed. This, of course, is a great annoyance to persons travelling on the road. To obviate this inconvenience two bells are placed in the gatehouse, one for up- and one for down-trains. These bells are in electric communication with the nearest stations, or signal-boxes, and warn the keeper of the approach of a train in either direction. Disk signals are placed 500 metres from the crossing in both directions and are set against the trains while the gate is open.

For the protection of trains upon steep gradients, a simple electric system has lately been introduced on lines with little traffic. A continuous current is established between two stations, and current-breakers are placed in each of the guard-houses between the stations, by which the men can signal to the stations. In the event of a train or a part of one running away down the incline, a signal can be sent to that effect to the nearest station. Another signal notifies that an accident has happened and that a breakdown engine is required.

Swing-Bridges.—Guards are stationed at each end of an opening bridge, and it is the duty of a guard when a train approaches the bridge to get on to the engine, and pass over with it.

Stations.—Up to the last few years, even at the larger stations, very simple signals were found sufficient, and these were independent of the points, but at many of the principal stations the traffic has now outgrown the original arrangements and interlocking points and signals are being introduced.

W. H. T.

Locomotives at the Turin Exhibition.

By Giovanni Sacheri, Engineer.

(Annuario scientifico ed industriale, Milan, 1885, page 581.)

Five different types of locomotive-engines for ordinary railways were shown at the Turin Exhibition.

The first, named the "Vittorio Emanuele II.," with six wheels coupled and front bogie, was built at the Turin railway workshops.

The second, with four wheels coupled and inside cylinders, called the "Verona," was built at the Verona railway workshops.

The third, designed for traffic on mountain lines, with eight wheels coupled, was built by Messrs. Ansaldo, of Sampierdarena, for the Alta Italia Railway Administration.

The fourth, built by the same firm for the Roman railways, has four wheels coupled.

The fifth, a goods-engine, with six wheels coupled, was built at the establishment of Pietrarsa e dei Granili (Naples), for the West Sicilian Railway.

The first of these engines is expressly designed to work the fast passenger-traffic on the new line now in course of construction between Turin and Genoa, which is intended to relieve the existing line, which crosses the Apennines by the Giovi tunnel, 3,400 metres (3,718 yards) long, and with gradients varying from 30 to 35 per 1,000 (1 in 33⅓ to 1 in 28½). The steadily-increasing traffic has rendered it necessary to construct a new line with lighter gradients, which shall not exceed 1 in 83⅓ in tunnels, and 1 in 62½ in the open. The Appennines will be passed at a lower altitude, but by a tunnel 8,262 metres (9,030 yards) in length, called the Ronco.

Although the goods traffic on the new line could be successfully worked by the present powerful locomotives with three or four pairs of coupled wheels, the new passenger-service will be very different, as on one section of the line, for a distance of 12,832 metres (7·97 miles), there are gradients varying from 1 in 62½ to 1 in 83⅓, and the present engines would not be capable of hauling at a high speed the heavy trains in both directions between Rome and Turin.

Under the new conditions, the problem to be dealt with was the construction of an engine capable of hauling a heavy passenger-train at a speed of 60 kilometres (37¼ miles) per hour on the level, and at the rate of from 40 to 45 kilometres (25 to 28 miles) on the steepest part of the line.

The engine has three pairs of coupled wheels, and a four-wheeled bogie in front. Its weight, empty, is 49,778 kilograms (48·9 English tons), and 54,531 kilograms (53·67 tons), in working order, of which a weight of 15,497 kilograms (15·26 tons) are supported by the bogie, and about 13 tons by each pair of coupled wheels.

The diameter of the wheels is 1·675 metre (5 feet 5·95 inches), and was adopted by the designer, in order that the tires should be of similar diameter to a large number in use on those lines, and also because, when running at the rate of 60 kilometres (37¼ miles) per hour, the piston-speed would not exceed 2 metres per second.

The wheel-base, not including the bogie, is 3·75 metres (12 feet 3·64 inches). The bogie-wheels are of the disk pattern, 0·84 metre (2 feet 9 inches) in diameter.

Another feature in this engine is the position of the cylinders, which are not placed, as is usually the practice, in the front of the engine, but immediately in the rear of the bogie, and this in order to obtain increased stability whilst running at high speeds; the cylinders are outside, and are 18 inches in diameter, with 24 inches stroke.

The valve-gear is of the Gooch type, and the eccentrics are carried on return cranks; the slide-valves work on inclined faces above the cylinders, and are lubricated automatically by an apparatus invented by Mr. Chiazzari, the principal locomotive superintendent.

The boiler is of a pattern capable of furnishing a large quantity of steam, and, rather than increase the number and length of the tubes, it was considered preferable to increase the direct heating-surface, adopting a larger proportion of grate-area, and greater lengths of combustion-chamber than is usually the practice. By such an arrangement the tube-plate is further removed from direct contact with the flame, and its duration materially will be prolonged. The number of tubes is two hundred and two, and their length 3·81 metres (12 feet 6 inches); the area of the grate-surface is 2·20 square metres (23·68 square feet), so that with a consumption per hour of 400 kilograms (81·95 lbs.) of coal per square metre, the necessary quantity of steam is produced.

The working-pressure is 10 atmospheres (147 lbs.) per square metre, the same as that of all the locomotives now constructed for the Alta Italia lines. The length of the boiler is 8·186 metres (26 feet 10·28 inches) over all; the diameter of the barrel is 1·369 metre (4 feet 5·9 inches), and the thickness of the plates 0·0155 metre (0·61 inch).

The smoke-box is fitted with a series of three truncated cones of sheet-iron, placed one under the other and communicating with the chimney; and in order that the draught in the lower tubes shall be uniform, the nozzle of the exhaust is kept as low as possible. The boiler is fed by two Friedmann's injectors, as well as by a Chiazzari pump, by which a continuous supply of hot-water is furnished.

The total length of the engine, measured over buffers, is 10·27 metres (33 feet 8 inches). The tender is of the usual type adopted by the Alta Italia Railway administration for powerful engines; it measures 6·06 metres (19 feet 10·58 inches) over buffers; the capacity of the water-tank is 8·20 cubic metres (290 cubic feet), and weighs, empty, 13,100 kilograms (12·8 tons), and 25,000 kilograms (24·6 tons) in working order. The evaporative power of the boiler is 5,580 kilograms (12·298 lbs.) of steam per hour.

The tractive force that this engine is capable of developing, when running at a speed of 60 kilograms (37 miles) per hour, is 2,585 kilograms (5,697 lbs.), and it is capable of hauling a load of from 100 tons to 102 tons at the speed of 60 kilometres (37 miles) per hour, up gradients of 8 per 1,000 (1 in 125); at a speed of 50 kilometres (31 miles) per hour up gradients of 12 per 1,000 (1 in 83½), and at 40 kilometres per hour (25 miles) on inclines of 16 per 1,000, 1 in 62½.

P. L. N. F.

Note.—Full particulars, with 16 lithographic drawings, &c., of the two first engines are embodied in a pamphlet published by the Alta Italia railway administration, entitled "Cenni sugli oggetti presentati alla esposizione generale Italiana di Torino dell' amministrazione della Strade Ferrata dell' Alta Italia e preparati dal servizio del Materiale." Torino, 1884.—P. L. N. F.

Colza Oil and Mineral Oil as Lubricants on Railways.

By L. Salomon.

(Revue Générale des Chemins de fer, April 1885, p. 216.)

On the Eastern Railway of France, simple colza oil has until recently been exclusively employed for the lubrication of the rolling stock. But, during the last four years, the petroleum oil of Pechelbronn (Alsace-Lorraine) has been exclusively used as a lubricant on the railways of Alsace-Lorraine; whilst a mineral oil, derived from the naphthas of the Caucasus, has been in use on the Western Railway of France, for the lubrication of locomotives: and Mr. Regray, the engineer of the Eastern Railway, decided to make a trial of the mineral oils on his express trains.

Practically, the excellence of a lubricant for the vehicles of a railway is usually proportional to the number of vehicles stopped by overheating of axle-boxes. Applying this test, colza oil appears as an excellent lubricant. For the last eight months of the year 1884 with pure colza oil, the average number of vehicles stopped by overheating of axle-boxes was 7·5, out of a stock of three thousand and ninety-eight vehicles; equivalent to 0·605 stoppage per one thousand axle-boxes in the service, and to 0·073 stoppage per one hundred thousand vehicle-miles run.

During the months of November and December 1874, and January 1875, colza oil deprived of margarine, was used for lubrication; and in the succeeding four months, a mixture of colza, horse-oil and resin-oil was used. The result of the change was that the number of stoppages by over-heating of axle-boxes on the system of Basson and Delanoy, was increased in the proportion of 19·3 to 26·3 monthly.

The mineral oil of Pechelbronn costs a little over 1*d*. per pound. It has given very satisfactory results, used in conjunction with white metal bearings, in respect of economy as well as of the reduction of the number of overheatings. The white metal, the result of two meltings, consists of 83⅓ per cent. of tin, 11·11 per cent. of antimony, and 5·55 per cent. of copper. It costs a little over 1*s*. per pound. On the Alsace-Lorraine Railways, the use of the mineral oil with white-metal bearings, reduced the number of heated boxes, as in 1873–79, in the ratio of 7·26 to 1, as in 1883–84. The cost of a lubrication of material for carriage and wagon stock has been reduced from £2,800 in 1877–78, to £950 in 1882–83.

D. K. C.

The Carrito Cocullo Tunnel. By LUIGI TREVELLINI, Engineer.

(Annuario Scientifico ed industriale, Milan, 1885, p. 469.)

The railway from Rome to Solmona follows the valley of the Aniene, and after passing the Monte Bove, it crosses the plain of Marsica, near the lake of Fucino, and enters the valley of the Giovenco, which it follows as far as Monte Carrito, in the main chain of the Apennines, which had to be pierced by a tunnel 3541·70 metres (3,871 yards) long.

The works were handed over to the contractors, Messrs. Campos and Co., on the 15th of January, 1882, and the following seven months were occupied in preparatory works, and for fixing the machinery for utilizing the water of the torrent Giovenco for motive power for driving the boring machinery, which was used on the western side; whilst the eastern side was tunnelled in the ordinary way by hand. The tunnelling by machinery was commenced on the 17th of September, Ferroux's boring-machines being used for this purpose, whilst the excavation by hand from the eastern face had already been commenced on the 13th of March previous.

The two drifts met on the 18th of June, 1884, or in six hundred and thirty-eight days, from which must be deducted seventy-nine days, during which the works were suspended on account of frost or snow.

The tunnelling was carried out on the so-called Austrian plan, that is to say, in the following order—1st, drift at level of formation; 2nd, upper heading; 3rd, removal of rock between top heading and bottom drift; 4th, excavation of rock to full section.

The works were carried out as follows:—From the roof of the drift at various distances apart a rise (*vertical shaft*) was driven to reach the height of the crown of the tunnel, and from these shafts or rises an upper heading was driven in both directions of the full section of the tunnel. In this way the number of working faces was multiplied to such an extent, that it was possible to push forward the works with great rapidity. In fact, the average daily advance was 5·40 metres (17·71 feet), which is considerably more than has yet been attained in the boring of any other tunnel under similar circumstances. The explosive used was supplied from the dynamite works at Avigliana.

The following shows the average daily advancement that has been made from a single face at some of the principal tunnels that have been driven by machinery:—

	Metres.	Feet.
Mont Cenis tunnel	1·75	5·70
St. Gothard "	2·75	9·02
Aarlberg "	4·15	13·64
Laveno "	4·50	14·76
Carrito "	5·40	17·71

P. L. N. F.

Improvements in the Arrangement and Rating of Current-Meters, and in the Method of calculating Discharges.

By Charles Ritter.

(Annales des Ponts et Chaussées, 6th series, vol. ix., p. 1058, 4 pl. and 13 woodcuts.)

A detailed account is given by the Author of the elaborate investigations which he conducted, with the object of rendering more serviceable the two gauging instruments generally employed in France, namely, Darcy's gauge-tube, and Woltmann's current-meter as improved by Mr. Baumgarten; for the purpose of facilitating the rating of these instruments; and lastly, for improving the methods of calculating the discharge from the indications furnished by the instruments. The ordinary type of gauge-tube is awkward to handle; and gauging with a current-meter which has to be drawn up out of the water for each reading is a slow process, especially at great depths. Moreover, the rating of these instruments has hitherto been frequently so difficult, slow, and costly, that either the rating has been dispensed with, thus introducing an uncertainty in the results, or the most favourable time for gauging has slipped by during the preliminary operations.

The gauge-tube adopted has the pressure-gauge distinct from the nozzles, which are connected together by india-rubber tubes. The rod carrying the nozzles is thereby made much more handy, whilst the observer can suspend the pressure-gauge so as to keep the summits of the two columns of water always in view, whose oscillations are considerably reduced by means of a regulator interposed between each india-rubber tube and the gauge. The nozzle pointing towards the stream has not been altered in type, but its best form consists of a straight tube 0·2 inch in diameter, and 4 to 6 inches long, tapered at the extremity, and presenting a cylindrical orifice of 0·08 inch in diameter throughout the tapered portion. The side nozzle, however, has been replaced by a statical mouthpiece, which indicates the pressure corresponding to the surface-level of the current without needing any correction. The mouthpiece adopted for this purpose consists of a tube, 4 inches long and 0·4 inch in diameter, open at both ends, and having a lateral orifice in the middle from 0·04 to 0·08 inch in diameter, round which the second connecting-tube is soldered. Each connecting-tube consists of two portions, one portion a rigid copper tube, and the other a flexible india-rubber tube. The copper tubes carry the nozzles at their lower extremities, and have an air-chamber at their upper ends with a stopcock at the top. Each air-chamber communicates with one of the india-rubber tubes by a lateral opening. The air-chambers receive the bubbles of air, either introduced by accidents in manipulation or contained in the water itself. The stopcocks serve for adjusting the instrument. The copper tubes should not be less than about $\frac{1}{4}$ inch diameter, to allow of the ready passage of air-bubbles into the air-chambers. The india-rubber tubes are made about $\frac{1}{6}$ inch internal diameter, for though they are little liable to receive air-bubbles, a very small diameter would impede the establishment of an equilibrium in the pressure-gauge. Their external diameter is made 0·4 inch, so that they may be bent without collapsing, which would impede the flow. The two connecting-tubes are enclosed in a hollow rod, 1 inch in diameter, which is provided with a vane at the bottom to facilitate the adjustment of the line of the nozzles. The pressure-gauge is furnished with a third tube to facilitate certain operations of rating. By the adoption of the statical mouthpiece, no rating is required, for the difference in the height of the two columns of water in the pressure-gauge *h*, is equal to $\frac{V^2}{2g}$, without any coefficient being required in the equation. Also the coefficient of gauge-tubes with any other side mouthpieces can be easily determined by connecting the mouthpiece with the third tube of the pressure-gauge and observing the heights of the three columns of water in different points of the stream. The most convenient instrument of the type described has a total length of 6½ feet, and is not suitable for depths exceeding 3½ feet; but by screwing on a lengthening piece to the rod it can be used for depths of 5 to 6 feet. This type of instrument is not suitable for considerable depths, both on account of the difficulty of handling an apparatus of over 10 feet in length when raised out of water, and also owing to the escape of air-bubbles when the pressure is reduced in the tubes by immersion, necessitating constant readjustments. These difficulties, however, might be obviated by using a different gauge-tube for each separate group of depths comprised within intervals of 5 feet.

The current-meter adopted has four spiral vanes, and is provided with an electrical recorder for every fifty revolutions. It is enclosed within a hollow copper cylinder 8 inches long, open at both ends, having a diameter of about 4½ inches, just large enough not to interfere with the revolution of the vanes. The cylinder protects the current-meter from the disturbing influences of oblique currents, and it facilitates the free suspension of the instrument which is directed in the line of the current by a large flat plate behind. The instrument is suspended in small depths, or near the surface, by a hollow copper rod; but in greater depths, when the length of rod necessary would be inconvenient, it is hung from a cord formed of two insulated copper wires, which convey the electrical current. The current-meter is kept in position by a second cord (kept tight by a weight at the bottom of the river, and a winch above) down which it descends, being guided by rollers. The rating, besides being conducted in the usual manner by drawing the meter through still water, was effected for small velocities by forming a very regular artificial current; and it was also obtained in the river itself, during the experiments, by placing the front nozzle of a gauge-tube in front of the axis of the current-meter and comparing the results of the two methods. When the velocity of a current is very small, the eddies produce almost as much effect as the direct current, so that the action of the vanes of the meter is uncertain; and consequently it is unadvisable to employ the current-meter for gauging currents having velocities under 1 to 1⅓ foot per second.

Owing to the variations and irregularities in the current, the velocities given by the instruments are always greater than the direct motion of the stream. Sometimes also, under exceptional circumstances, the recorded velocities are too low. Accordingly, in order to make allowance for these discrepancies between the real and calculated results, the mean of two-thirds of the largest velocities, and the mean of two-thirds of the least velocities are taken, and half the sum of these two means is accepted as the actual mean velocity in the section. The mean velocities throughout the whole section can be obtained by tracing the lines of equal velocity, as gathered from the observations, and prolonging these lines, in accordance with the indications furnished by the adjacent lines, to those parts of the section which cannot be reached by the instruments. The article concludes with some practical applications of the above methods of gauging, in illustration of the processes adopted and the degree of accuracy attained.

L. V. H.

The Villoresi Canal. By LUIGI TREVILLINI.

(Annuario Scientifico ed Industriale, Milan, 1885, p. 480.)

The Villoresi canal serves to irrigate the tract of country between the Naviglio Grande and the Martesana canal. It has been recently constructed by the "Società Italiana per condotte d'acqua" of Rome, and was opened last April.

The water for this canal is derived from the Ticino at a place called Rapida del Pamperduto, by means of a weir thrown across the river. This weir is 290 metres (951·2 feet) long, and 24 metres (78·72 feet) broad, and of sufficient height to raise the water in the Ticino 3·75 metres (12·30 feet), above the ordinary low-water level. The weir is built of concrete, faced with granite blocks. Below the right abutment the river-bank is protected by a wall for a distance of 50 metres (164 feet), whilst upstream, on the same side, an embankment, partly in masonry and partly in earthwork faced with stone pitching, has been constructed for a distance of 600 metres (1,968 feet) in order to confine the river to its present bed.

The headworks, which are on the left bank, consist of a building 67 metres (219·76 feet) long, 6 metres (19·68 feet) wide, and 12·80 metres high, provided with thirty sluices, each of 1·50 metre (4·92 feet) clear width, and 3·25 metres (10·66 feet) high, the sills of which are placed at 2·75 metres (9·02 feet) below the level of the crest of the weir. These sluices are capable of admitting 190 cubic metres (6710·13 cubic feet) per second into the canal from the river, of which 70 cubic metres (2472·15 cubic feet) per second is the amount granted by the concession to the Villoresi canal. The remaining 120 cubic metres (4237·98 cubic feet) per second have to be returned to the Ticino, by a specially constructed measuring weir established at 600 metres below the headworks, in order to respect the existing rights of others further down stream. The passage of boats from the Ticino to the canal is provided for by means of a channel with lock 8 metres (26·24 feet) wide.

The first section of the canal commences with a breadth of 67 metres (219·76 feet) at the headworks, which is gradually reduced to 43 metres (141·04 feet), is 600 metres in length, with a depth of water of 3 metres (9·84 feet), terminating in a basin, on the sides of which are placed the following works: 1st, a measuring weir, consisting of a massive masonry wall, the crest of which is placed 0·90 metre (2·95 feet) below the surface-level of the water in the canal, in order that a volume of 120 cubic metres (4237·98 cubic feet) per second may be discharged over it. The water flowing over this weir falls a vertical height of 4·60 metres (15·08 feet), into a deep basin which acts as a water-cushion, and from thence into the river.

At right angles to the weir is a lock with a drop of 6 metres (19·68 feet), the largest in Italy, which serves for the passage of boats from a channel below, 10 metres (32·8 feet) wide and about a kilometre (0·62 mile) long, from the canal to the Ticino. This channel is supplied with water from the basin below the measuring weir by means of four sluices 0·80 metre by 1·20 metre (2·62 feet by 3·93 feet) placed in the wall which separates the basin from the canal. On the side of the basin opposite the weir are two buildings, the first containing the sluices, which admit 8 cubic metres (282·52 cubic feet) per second of water into a canal belonging to the Visconti family; and the second, which forms the entrance to the Villoresi canal, serves to regulate and maintain the level of the water in the basin constantly at 0·90 metre (2·95 feet) above the crest of the weir. It consists of a three-storied building, in the lower part of which are six sluices, 2·30 metres (7·45 feet) wide, and 3 metres (9·84 feet) deep, with iron gates, worked by suitable mechanism from the floor above.

The canal below the sluice-house may be divided into two distinct sections, the first of which is 16 kilometres (9·94 miles) long, and serves to convey the water to the tract of country to be irrigated; while the second, which will eventually extend for a distance of 64 kilometres more (39·76 miles), further serves at the same time as a feeder for the secondary network of irrigation-canals.

The first section has a width at bottom of 11 metres (36·08 feet), with sides sloping 1¼ to 1, and a fall of 0·25 per thousand (15·83 inches per mile); it is capable of carrying 50 cubic metres (1765·83 cubic feet) per second, with a depth of 3 metres (9·84 feet), which can be increased to 72 cubic metres (2542·78 cubic feet) per second, with a depth of water of 3·50 metres (11·48 feet). In consequence of the permeability of the soil (gravel and sand), it was found necessary to line the bottom of the canal with a layer varying from 0·10 to 0·20 metre (4 inches to 8 inches) in depth of concrete, and to revet the sides with a stone pitching. The bridges on this section are all of iron, of a uniform span of 19 metres (62·32 feet) and 7·80 metres (25·58 feet) above the bottom of the canal, in order to allow of sufficient headway for the passage of boats.

As yet only 29 kilometres (18 miles) of the second section have been constructed. It varies in width at bottom from 13 metres (42·64) to 10 metres (32·8 feet), with sides sloping 1½ to 1, and falls 0·15 per 1,000 (9½ inches per mile). From this canal there are seventeen derivations of water, varying in volume from 300 litres (10·59 cubic feet) to 10 cubic metres (353·16 cubic feet) per second.

Upwards of 120 kilometres (74·65 miles) of secondary canals have already been constructed by the company, and comprise no fewer than six hundred separate works, such as bridges, aqueducts, reversed siphons, and falls, which last are capable of furnishing upwards of 3,000 HP.

The network of small distributing canals will ultimately exceed 1,000 kilometres (621 English miles) in length.

P. L. N. F.

The Castelnovate Cutting on the Villoresi Canal.

(Il Politecnico, 1885, p. 249.)

The length of the cutting along the centre line of the canal is 1,140 feet, and the mean depth 86 feet. The ground consists principally of gravel, sand, and pebbles. The section of the cutting is thus described:—Width at bottom of canal, 33½ feet; depth from the bottom to the towing-path, 12½ feet; slope, 1¼ to 1. The towing-path is 6½ feet wide; above it the slope is 1½ to 1. At each vertical height of 20 feet is a bench 5 feet wide. On the side of each bench, and extending through the whole length of the cutting, is a dry stone wall, having an external batter of 1 in 6, each wall being 5 feet high and 1½ foot thick at the top. The slopes are covered with a layer of vegetable soil 1 foot thick, sown with grass. The bottom of the canal is paved with concrete, 4 inches thick, over which is spread 12 inches of gravel. The slopes, to a height of 4¼ feet above the concrete, are lined with pebble pitching in hydraulic mortar, and for another 3¼ feet with dry pitching grouted; above this, for another 6 feet, on to the level of the towing-path, dry pitching is used. At intervals of 165 feet drains are laid down the slopes. These drains are 2 feet 7 inches wide, and 6 inches deep. They are made of pebbles set in hydraulic mortar; they are carried across the towing-path, and discharge into the canal. At the foot of each of the retaining-walls, and running all along each bench, is a drain similarly constructed, 1 foot 8 inches wide and 4 inches deep. These drains receive the water which flows off the slopes, and convey it into the transverse drains. Along the top of the cutting on each side a drain is cut (which also discharges into the first-mentioned drains), to intercept the water flowing off the land, and prevent it from running down the slopes. The gradient of the bottom of the canal is 0·25 metre per kilometre (1 in 4000). The total content of the cutting was 502,000 cubic yards. Details are given in the Paper of the method of executing the work.

W. H. T.

Notes on Canal-Lifts and Inclines.[1] By J. Vandrunen.

The power of the canal lock is limited because its height of lift cannot exceed 12 or 15 feet; the passage through it of boats is slow, and leads to blocking up the canal; and it consumes a quantity of water which is sometimes considerable. These disadvantages of the lock have led engineers to devise means for superseding it; they may be divided into two classes, viz., lifts and inclines, the principal examples of both which are described.

On account of the failure of two hydraulic presses for lifts, one of cast-steel which burst under a pressure of 70 atmospheres, and another of steel-plate riveted, which leaked and also rent under pressure, the Cockerill Company made a trial hydraulic cylinder for the Brussels and Charleroi Canal, in which, however, it has since been decided to supersede the lift by a tunnel. In this cylinder, tightness is obtained by cast iron and strength by steel; that is to say, the cast-iron cylinder is hooped with steel bands, rolled in one piece like railway tires. The cylinder is cast with projecting rings, turned to receive the hoops, which are bored to a slightly smaller diameter, put on hot and allowed to contract. A cylinder, 2·06 metres (6 feet 9 inches) in diameter and 2 metres (6 feet 7 inches) high, was subjected, by means of force-pumps, to an internal pressure of 131 atmospheres, or four times that which would be required in practice. The French engineers, following the Seraing system, formed their cylinders of a series of steel hoops fitting one into the other, and with the flanges of the two outside hoops drawn together by tie-rods, the inside being lined with brass 0·0025 metre thick, applied with the mallet, so that the water may not come into contact with the joints. A trial cylinder was tested up to 170 atmospheres without yielding.

The Author concludes that the results obtained warrant the belief that hydraulic lifts for canals may be made sufficiently strong to work with safety; but he also considers that inclines possess the advantage of correcting some faults which it would be difficult to eliminate from the use of lifts.

J. W. P.

Canal-Traction.[2] By J. Ragoni.

The Author divides the means for traction on canals into two classes, those which have their fulcrum in the water, as paddle-wheels and screw-propellers, which only utilize about 40 per cent. of the power and damage the banks, and those in which it lies out of the water, as in the following systems:—

Grapplers, used for towing boats in the strong current of the Rhone, consist of a keel carrying at the stem or prow a large wheel with cams, which, immersed in the stream and set in motion by a steam-engine, draws the boat along by pushing against the bottom.

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[1] Paper prepared for the International Congress on Inland Navigation, held at Brussels, from 24 May to 2 June, 1885. The original is in the Library of the Inst. C.E.

[2] *Ibid.*

In ordinary chain towage, by which about 70 per cent. of the power is utilized, an endless chain or rope is laid along the bottom of the canal, in lengths of 2 or 3 miles; and the tug is drawn along by the engine pulleys engaging with the rope or chain, allowing the slack to fall down behind.

In endless-chain towage, which is a new system, tried on the Rhone, suitable for rapid currents, the tug carries two independent engines, each of which puts in motion an endless chain drawn along by the tug. This chain receives a motion like that of the bucket chain of a dredge; but the upper portion remains horizontal, while the lower follows the bottom of the canal, the length and weight of the chain being determined by the adhesion necessary for drawing along the tug. In going round curves, the speed of one of the engines is reduced.

In towage by locomotive, a narrow-gauge railway is laid along the bank; and the locomotives draw the boats in the same way as horses do. This system is employed on the canals of the Deule and Neufossés, for a total length of 80 kilometres (50 miles). The line is of metre gauge, laid with Vignoles rails 30 lb. to the yard. There are twenty-two locomotives, weighing from 6 to 11 tons, each of which is capable of drawing 1,000 tons at a speed of 2 kilometres (1¼ mile) an hour.

The Author dwells chiefly on a new method of traction by a running rope, in which an endless steel rope is kept constantly running along the banks, at a certain height above the water, by means of stationary engines, erected from 6 to 8 kilometres apart, and each driving two portions of 3 to 4 kilometres length. The boats are hitched on to the running rope by a towing line with special clip, at a speed determined by local circumstances. Arrived at the end of one section, they are detached and hitched on to the next without any appreciable diminution of speed. On straight portions, the guide-pulleys for the running rope are placed in a vertical plane, but on curves they are inclined. At the ends of the sections, the running rope is carried either above or below the canal, as it runs on both sides for the up and down traffic. The endless ropes are kept stretched by a truck, chain and counterweight, to which a hydraulic brake is added for deadening the shocks due to hitching on and releasing the boats to be towed. The principal feature in this system is the clip, the latest pattern of which is capable of assuming three several positions while passing the pulleys without lifting the running rope, viz., slipping loosely along it, tightening itself on the rope, and letting go altogether. There is an appliance for giving release automatically, in the event of sudden obstruction, and another for allowing the tow line on starting to slip, gradually less and less, until the boat acquires the speed of the running rope.

J. W. P.

The Buoys of the Tidal Scheldt. By J. Boulvin.

(Annales des Travaux Publics de Belgique, vol. xli., p. 147, 1 plate.)

From the great variety of types of buoys employed during the last thirty years, it is evident that there is some difficulty in designing a buoy which shall be perfectly stable and always visible, exposed to waves and currents, and where, as on the Scheldt, drifting ice has sometimes to be encountered. The long slender Hamburg buoy has been tried on the Scheldt; owing to its slight stability, it dips under the drifting ice and reappears again as soon as the surface is clear; but it was found that it was not visible enough, and that it disappeared too readily. Three types of buoys have been adopted on the Scheldt, namely, (1) summer buoys of the ordinary can type, placed near together, to mark the channels, and not requiring to be seen far off; (2) winter buoys, specially constructed to resist the drifting ice in the most exposed situations; and (3) sea buoys to mark sand-banks at the mouth of the Scheldt.

The ordinary summer buoy has the shape of half an egg. It is made of plate-iron, $\frac{1}{8}$-inch thick; its height is 5 feet 10 inches, and its top, $3\frac{1}{4}$ feet in diameter, is provided with a man-hole. A horizontal plate-iron partition about halfway down adds much to its stiffness. These buoys weigh 463 lbs.; they cost about 2·68*d.* per lb., and have proved very satisfactory.

The winter buoy has been specially constructed to withstand ice-drifts. It has consequently been given an elongated ovoid form, of a type midway between the slim American spar buoy and the ordinary rounded sea buoys, and has its ballast and point of connection placed as low as possible so as to dip readily under the ice-drifts. The buoy has a diameter of $4\frac{1}{3}$ feet in the centre, and a length of 10 feet 2 inches, exclusive of the cone above, and the ballast and connecting line below. It is anchored by a $\frac{7}{8}$ inch cable, with anchor stones of 24 cwts. The buoy is of plate iron, and is divided into three water-tight compartments by two horizontal diaphragms; access to the interior being provided by a manhole at the side of the buoy and in each diaphragm. An iron rod fastened to the bottom extremity of the buoy carries the ballast of 624 lbs., consisting of eight cast-iron disks. These buoys cost 2·63*d.* per lb.; their total weight is 2,705 lbs., of which 1,845 lbs. is wrought-iron and the remainder cast-iron. These buoys resemble in form the wooden buoys employed by the Dutch, but they are much more durable.

The sea buoy of the most recent form consists of two truncated cones, united at their base by a cylindrical portion 7 feet in diameter. The buoy is of iron, and is divided into two water-tight compartments by a partition at the base of the upper cone; its total height, with the ball at the top, is about $16\frac{1}{2}$ feet. The plates of the upper half of the buoy are $\frac{1}{5}$ inch thick, and $\frac{1}{4}$ inch in the lower portion. The cylindrical part of the buoy, at the line of flotation, is protected by an elm fender encircling the buoy. The ballast, consisting of cast-iron plates, is placed inside a cast-iron box fastened at the bottom of the buoy. The connection with the anchor chain has been made by rods attached to each side of the buoy, as near the water-line as possible, and fastened to a link below, so that the action of the waves on the buoy may be as much below as above the point of connection, which keeps the buoy more erect and throws less strain upon the chain than in the older type where the connection was at the bottom. These buoys are anchored in 20 feet of water by a 1$\frac{1}{7}$-inch chain 100 feet long, and their stability is greater than that of the older buoys. The total weight of the buoy is 4,753 lbs., of which 1,234 lbs. are the weight of the cast-iron box and ballast. The cost of these buoys is 2·63*d*. per lb. at Ostend. One of Mr. Pintsch's light-giving buoys was placed in 1882 on the Wandelaar bank in front of Blankenberghe, but it has been replaced by a light-ship.

L. V. H.

The Wandelaar Light-Ship. By J. Boulvin.

(Annales des Travaux Publics de Belgique, vol. xli., p. 415, 3 plates.)

The Wandelaar bank lies to the north of the Wielingen channel, which furnishes the approach to the Scheldt, and it has barely 23 feet of water over it at low water. Till September 1882 this bank was only marked by a large buoy which was not easily recognized at night or in foggy weather. The light-ships of West-hinder and Wielingen were the only marks for guiding vessels coming from the English Channel to the entrance of the Scheldt, and it was accordingly determined to place an intermediate light-ship on the inside of the Wandelaar bank. The Wandelaar Light-ship differs in several arrangements from the Seven-Stones light-ship off the Scilly Isles, and from the Dutch light-ships of Schouwen Bank and Terschelling; but, like them, it is furnished with a siren of the first order for foggy weather. Accordingly the vessel kept in reserve for the other two light-ships could not be used as a substitute for the new light-ship; and therefore two identical vessels had to be constructed, so as to have one in reserve in case of need. These light-ships are described in detail by the Author, and are fully illustrated in the plates. They were contracted for in September 1881; Messrs. Cockerill and Co. undertaking the vessels, Messrs. Chance Brothers, of Birmingham, the lights, and Messrs. Brown, of New York, the sirens and engines. The vessels were fitted out at Antwerp, towed to Flushing, and one of them was anchored in position in September 1882, in a depth of 30 feet at low water; the two together cost complete £18,264. The flashes of the light occur at intervals of five seconds. The siren is worked by air at a pressure of two atmospheres, and is placed in the centre of the vessel. A continuous sound would involve too large an expenditure of air, so the siren emits two notes, close together, each lasting 2½ seconds at intervals of 2 minutes. During the trial of the siren, when the vessels were on the Scheldt, the sound could be heard, over a densely-wooded country, at a distance of 6¼ miles, which approximates to the limit that can be attained by such instruments. In eleven months, from October 1882 to September 1883, there were sixty-two cases of fogs; July alone was perfectly clear, whilst in December the siren was set in action on eighteen different occasions for a total period of eighty-two hours; and in January the fog lasted on one occasion for thirteen hours. By the help of the siren, continuous signals have been given without any interruption.

L. V. H.

Large Blasting Operations with Dynamite in Italy.

By Luigi Trevellini.

(Annuario Scientifico ed Industriale, Milan, 1885, p. 453.)

The first blasting operation on a large scale with dynamite in Italy took place in July, 1883, at the quarry of Bergeggi (Liguria), from which the stone used for the construction of the new port of Savona is obtained. The quarry face is from 35 to 40 metres (115 feet to 131 feet) in height. The preparatory works consisted of a gallery 2 metres (6·56 feet) high, by 1·20 metre (3·95 feet) wide, driven horizontally into the mountain at a height of about 8 metres (26·25 feet) above the bottom of the quarry for a distance of 16 metres (52·5 feet) from the end of which a second was driven at right angles, but at a level of 2 metres (6·56 feet) below it; from the end of this gallery, and in a parallel direction to the first, a third gallery 5 metres (16·4 feet) long was driven; at the end of this and on one side a circular shaft 1·50 metre (4·92 feet) in diameter was sunk to a depth of 2 metres (6·56 feet). The position of this shaft, which served as a chamber for containing the explosive, was therefore 21 metres (68·88 feet) from the quarry-face, and its height above the floor 4 metres (13·12 feet).

The amount of charge was determined by the following formula, $c = K\,g\,W^3$. c being the charge of dynamite, K a constant $= 0 \cdot 34$; g a veritable coefficient from 1 to 2·50; and which in the present case was 1·7; W, the line of least resistance. The quantity of dynamite required, as found by this formula, was therefore 3,000 kilograms (6613·86 lbs.). The explosive, contained in sacks coated with paraffin wax, and weighing 42 kilograms (92·4 lbs.) each, was carefully laid in the chamber, and on the top of the first layer of sacks, a priming cartridge 1 metre long (3·28 feet) was placed, and on that were laid a certain number of detonators, half of which were connected with the conducting wires of the electrical apparatus used for firing the charge, whilst the others were connected with a safety fuze. The remainder of the sacks containing the dynamite were then packed in the chamber, an operation occupying three hours. The vacant space above the charge was next filled in with sand-bags, and the gallery closed with a masonry wall built in cement, for a thickness of 2·50 metres (8·2 feet), the remainder of which as well as the second gallery to within 2 metres (6·56 feet) of its junction with the first, were next filled up with rubble masonry carefully built with cement mortar. The remainder of this gallery was filled with dry walling, the stones being carefully packed and strutted against the side of the first gallery by strong timbers. The first gallery was left unfilled. The conducting-wires and the fuze were passed through the masonry in lead pipes 3 millimetres (0·19 inch) in internal diameter for protection.

The operation was attended with satisfactory results; 20,000 cubic metres (26,160 cubic yards) being loosened by the explosion, which was considerably more than had been anticipated.

The success of this experiment encouraged the contractors for the works of the Port of Genoa in the following August to undertake blasting operations on a still more considerable scale, a charge of 5,000 kilograms (11,023 lbs.) this time being used. The gallery, which was 1·20 metre (4 feet) high by 0·90 metre (3 feet) wide, was driven in a zigzag fashion and terminated in a vertical shaft, 1 metre (3·28 feet) in diameter, and 8 metres (26·25 feet) deep, at the bottom of which was placed the charge. After the explosion it was found that the rock had been loosened for a distance of 10 metres (32·8 feet) behind the blasting chamber, and that 120,000 cubic metres (156,962 cubic yards) of stone had been obtained. The dynamite used in both cases was manufactured at Avigliana.

P. L. N. F.

On Reservoir-Basins and Sea-Sluices for Draining Low-lying Lands. By G. Scarpari.

(Giornale del Genio Civile, 1885, p. 172.)

When an area of land has to be drained into the sea, but the level at which the water has to be discharged is between low- and high-water mark, so that the discharge can only take place at certain periods of the tide, it is usual to provide one or more sluices, worked automatically, and a collecting-basin behind them into which the water may flow when the sluices are shut.

It is a matter of great importance that the area of the sluices, and that of the collecting basin, should be so regulated that the former may be open for as long a period of time as possible, so as to hinder the heading up of flood-water, and that they may act as efficiently at ordinary tides as during floods.

The basin must be of such extent as to contain so large a proportion of the volume brought down by the canals that the surface may not rise to the level of the flood-tide till the moment at which the tide begins to ebb. In designing such works, a diagram should be prepared showing the rise of the tide and that of the water in the basin, so as to show the period during which the sluices may be open. When the range of any tide is known, the rise above the low-water of that tide at each hour may be found by multiplying the total height of the tide by the following figures:—

Hour . . .	0	1	2	3	4	5	6
Multiplier . .	0	0·067	0·250	0·5	0·75	0·933	1·0

Owing to the difference in specific gravity between salt-water and fresh, the latter must always have a head over the former in order that there may be a discharge when the sluices are open. If a = the depth of the sill of the sluice below sea-level at any moment, the head must be $0 \cdot 0279\, a$.

The Author investigates the relations between the volume of the drainage-water, the area of the collecting-basin, the depth of the sill, the length and lift of the sluices, and the rise of the water in the basin. He gives, as an example of the application of his formulas, the case of the lowlands of the province of Rovigo, which are drained into the Adriatic. In this case the volume flowing into the collecting-basin is 40 cubic metres per second, and the area of the basin has been fixed at 3,000,000 square metres. In regard to fixing this area, it must be remembered that the larger it is, the smaller will be the rise of the water in it during a given time, and consequently the time during which the tide will be low enough for discharge to take place will be less than with a smaller basin, and hence the width and depth of the sluices must be greater. In the example given, the lift of the sluice above low-water is found to be 0·5299 metre, and, the depth of sill being assumed at 4 metres below low-water, the maximum height of the water in the basin above the same level should be 0·5472 metre, and the total length of sluices 71 metres.

W. H. T.

Pumping in the Low Countries.[1] By A. Huet.

The consumption of fuel in the pumping-engines of Holland is generally 3 kilograms (6·6 lbs.) per actual HP. per hour in water raised; and for Archimedean screws driven by steam, the consumption is scarcely less. In water-raising wheels it is reduced to 2·5 kilograms (5·5 lbs.), which differs little from the consumption of lifting and forcing horizontal pumps. Centrifugal pumps have generally a consumption of 3 kilograms (6·6 lbs.), which is sometimes reduced to 2·37 kilograms (about 5 lbs.). There are two good reasons why this consumption should be reduced, and the figure of 1·5 kilogram (3·3 lbs.) be obtained per HP. in the case of an almost constant lift. The application of the compound system permits of reducing the consumption per HP. at the cylinder to 1 kilogram (2·2 lbs.), which, with a useful effect of 66 per cent. in the whole apparatus, gives a consumption of 1·5 kilogram (3·3 lbs.) per actual HP. per hour. This duty may be obtained with the lifting pumps of the late Mr. A. Lipkens, used for draining the Haarlem Meer, and with the forcing pumps introduced into the Low Countries by Mr. Fynje, formerly chief inspector of the Waterstaat.

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[1] "Stombemaling van Polders en Boezems, door A. Huet. s'Gravenhage de Gebroeders van Cleef, 1885." A copy is in the Library of the Inst. C.E.

J. W. P.

The First Artesian Well Boring in the Roman Campagna.

By Luigi Trevellini.

(Annuario Scientifico ed Industriale, Milan, 1885, page 486.)

The supply of potable water in the Roman Campagna is one of the most urgent necessities that has to be provided for in the carrying out of the project for the improvement of this vast district. In order to provide with water one of the forts recently constructed for the defence of Rome, a boring was made by the military authorities for this purpose. This fort is situated near the tomb of Cecilia Metilla, on the Appian Way, about 2½ miles beyond the city walls, and at 70·30 metres (230·58 feet) above the level of the sea. The results, not only from a geological point of view, are most interesting, as the volcanic formation was passed through; whilst, on the other hand, they show the advantage that may be derived from boring, as water, both for irrigation and potable uses, may be obtained by this means, for at a depth of 42·12 metres (138·15 feet), or 28·18 metres (92·33 feet) above the level of the sea, the first water-bearing stratum was found in the volcanic deposits; whilst a second was reached at a depth of 83·30 metres (273·22 feet), or 13 metres (42·64 feet) below the level of the sea in the quartertiary formation. The bore-hole, which was 32 centimetres (12·6 inches) in diameter, was carried down to the depth of 90 metres (293·2 feet) below the surface. Kind's percussion boring apparatus was used for sinking the well.

P. L. N. F.

Examination and Testing of the Berlin Water-Supply.

(Gesundheits-Ingenieur, July 15, 1885, p. 383, and July 31st, p. 417.)

The testings of the Berlin water during the period from July 1, 1884, to April 1, 1885, have been regularly carried out, in accordance with the plan agreed upon between the Director of the

Municipal Waterworks, Mr. Gill, M. Inst. C.E., and the civic authorities. The chemical analysis was arranged as follows:—

1. Estimation of the residue from the evaporation of 200 cubic centimetres of water, dried for five hours at 110° Centigrade.

2. Estimation of the volatile portion of the residue by calcination, moistening the ash with carbonate of ammonia and again calcining it at a low temperature.

3. Estimation of the chlorides by titration of 200 cubic centimetres with $\frac{1}{10}$ normal silver solution, according to Mohr's system.

4. Estimation of the ammonia (after separation of the lime, magnesia, iron, &c., by means of soda-lye and carbonate of soda) by calorimetric tests of the liquid decanted from the residue, with Nessler's solution.

5. Estimation of the lime by titration of the amount of oxalic acid necessary for the precipitation of the lime, by means of chameleon solution, on Mohr's system.

6. Estimation of the oxidizability in a solution of sulphuric acid, on boiling for ten minutes, on Kubel's system.

The investigations for micro-organisms were both microscopical, and by means of pure cultivation on a solid medium (10 per cent. meat juice-pepton-gelatine).

Few variations in the chemical composition of the water of the Spree and that of Lake Tegel were observed, but the contents in micro-organisms fluctuated considerably. The Spree water is richer in chlorides and in substances capable of being reduced in an acid solution by the chameleon tests, also in fertile germs of micro-organisms. An appreciable amount of ammonia could only be found in the Spree water, and this reached on one occasion 0·23 milligram per litre. The water of Lake Tegel only showed on one day a measurable quantity of ammonia, viz.: 0·04 milligram per litre. The efficacy of the sand-filters is next examined. On all occasions the contents in organic matter, chlorides, the oxidizability, and micro-organisms were reduced by filtration, but the dissolved lime was slightly increased. The tests on March 2nd showed that the filtration had only reduced the fertile germs in each cubic centimetre from 963 to 468, whereas in the previous week the reduction had been from 210 to 68, and in the previous fortnight from 250 to 28. This led to an exchange of correspondence with the Engineer, and to the discovery that, owing to the formation of a thick sheet of ice over the uncovered filter-basin, it had been impossible to cleanse it.

Daily examinations were made of the water from each of the filter-beds, to test their action with respect to yield, endurance, rapidity of yield under pressure, and influence of temperature, and these tests were made in comparison with the unfiltered water. Comparative investigations were also made respecting the efficacy of open and covered filter-beds, and the fact was established that the open filter-bed removes considerably more fertile germs than the covered one. Precautions were taken to test most carefully for the *crenothrix polyspora*, both in the freshly-collected samples and in those which had stood for twenty-four hours, but on no occasion was the presence of this conferva detected by microscopic examination of the water from the Spree. It was, however, often present in the water of Lake Tegel. The investigations generally prove that the water-supply is rendered more or less impure after leaving the source, either by the distribution through the pipes or by storage in the high-pressure reservoir at Charlottenberg. Nothing has, however, transpired to indicate, either chemically or microscopically, the presence of injurious agents of any description in the water of Berlin.

G. R. R.

The Venice Waterworks. By Luigi Trevellini.

(Annuario Scientifico ed Industriale, Milan, 1884, p. 441.)

This important work was carried out by the "Società Veneta di Costruzioni ed Opere Pubbliche," and under conditions of exceptional difficulty, on account of the configuration of the city, and the numerous canals which had to be crossed by the mains.

The supply is drawn from the river Brenta, near Stra, from which the water is conveyed in an open channel, 2·60 metres (8 feet 6·3 inches) wide at the bottom, 1 metre (3 feet 3 inches) deep, and with a fall of 1·31 metre (4·2 feet) on its total length of 7,300 metres (7,978·9 yards) to the Seriola Veneta,[1] and from thence by that channel to the shore of the Lagoon near Moranzani. The quantity of water conveyed by this channel is 1,500 litres (330 gallons) per second, part of which is drawn off into the filter-beds, whilst the remainder furnishes the motive power to the Girard turbines. These drive the pumps which raise the filtered water to a vertical height of 6 metres (19 feet 8 inches) into an iron tank that forms the pipe-head chamber of the line of mains laid under the lagoon to the service-reservoir in Venice. The filter-beds are four in number, 306 square metres in extent each, and cover a total area of 1,224 square inches (13,175 square feet). The sides are in brickwork, and the floor concrete. The filtering material consists of a layer of large stones laid on the concrete floor, over which there is a bed of coarse gravel 43 centimetres (16·9 inches) in depth, which is followed by a layer of fine gravel 20 centimetres (8 inches) thick, covered with another of fine sand. The main under the lagoon is of cast iron 6,426 metres (7,023·6 yards) in length, 80 centimetres in diameter (31½ inches), and 18 millimetres (0·70 inch) thick. It is supported on a timber cradle, consisting of two piles and a cross timber, to which the cast-iron main is firmly secured; these cradles are placed 2 metres (6 feet 6 inches) apart. In consequence of the depression in certain places in the bottom of the lagoon considerable difficulties were encountered in the laying of the reversed siphons, one of which, under the Donena canal, near the Maritime station, was 215 metres (235 yards) in length, and for laying it divers were employed. The service-reservoir from which the water is pumped up to supply the city is situated near St. Andrea. It is constructed entirely in brickwork, and covered with arches supported on piers. This reservoir is 67·10 metres (220 feet) long, and 23·90 metres (78·4 feet) in breadth, with a depth of 5 metres (16·4 feet) of water. Its capacity is 10,000 cubic metres (2,200,970 gallons). The pumping engines are of the compound type, and are each 50 nominal HP. The mains for the distribution of water in the city have an extension of 27 kilometres (29,528 yards), and vary in diameter from 60 centimetres (23·62 inches) to 8 centimetres (3·14 inches), and supply 121 public cisterns. P. L. N. F.

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[1] The Seriola Veneta is an open canal made in the sixteenth century (when the population of the city was double that which it is at the present time), for the purpose of supplying Venice with water taken from the river Brenta near Dola. This channel terminated on the shore near Moranzani, and the water was conveyed across the lagoon in boats to fill the public cisterns.—P. L. F. N.

Prevention of Water-waste in St. Louis. By M. L. Holman.

(Journal of the Association of Engineering Societies, August 1885, p. 368.)

In December and January, 1883–84, the consumption of water in the city of St. Louis was so great that the pumping-engines were unable to keep up with the demand. The excessive demand was occasioned by the consumers allowing water to run to waste to prevent it from freezing in the service-pipes. A system of house-to-house inspection, established under the superintendence of the Author, was initiated on the 8th of January, and was maintained until the 19th of the same month, resulting in a saving of water to such an extent that the supply was ample in all parts of the city.

The method of inspection consisted, first, in ascertaining if water was passing through the stop-cock by which the supply to the premises was controlled; and following this up with an inspection by the day force to find the cause and stop the waste. For the defection of flow of water through the stop-cock, the ordinary iron key for turning the cock was flattened out so that the ear could be pressed tightly against it. The least flow detected by this means was a little less than five gallons per hour. The average night consumption during the two months, January and February, for the five years 1879–1883, was 817,000 gallons per hour; and for the year 1884, under inspection, it was only 599,000 gallons per hour, showing a saving of 218,000 gallons per hour. For the day consumption, 1,128,500 gallons per hour were consumed, against 950,000 under inspection, making a saving of 178,500 gallons per hour.

But the system of inspection became very onerous to the watertakers. Some persons expect to defeat inspection by filling the stop-boxes full of sand; others tried old shoes, hard coal rammed down, &c. All sorts of excuses are offered to explain the flow of water through the stop-cocks during the night. The inspection can only be made efficient by keeping a very expensive force of inspection, backed up by complete legislation.

D. K. C.

Water-ram in Pipes. By E. B. Weston.

(Transactions of the American Society of Civil Engineers, June 1885, p. 238.)

Mr. Weston records the results of experiments for water-ram conducted by him, on the Providence R. I. Waterworks. Lines of pipes were laid above ground, from 1 inch to 6 inches in diameter, with an air-chamber that could be connected or disconnected as required. The efficiency of this air-chamber may be judged by the fact that whilst a static pressure of 70 lbs. per square inch caused the water-level to rise to within 10 inches from the top, a force of ram equivalent to 35 lbs. above static pressure caused the level to rise to within 9 inches from the top. The water-supply was taken from a 6-inch pipe proceeding from the 24-inch mains.

The ram was produced by suddenly closing a valve in the outlet pipe, after the water had been flowing for a short time. It could be closed in about 0·16 second. The force of ram was regulated by using nozzles having orifices of different sizes, from $\frac{1}{16}$ inch to ½ inch diameter, connected as required to the outlet pipe; and was measured by a Richards indicator. The average static pressure was 70 lbs. per square inch.

In the first series of experiments, the water flowed through 111 feet of 6-inch pipe, 58 feet of 2-inch pipe, and 99 feet of 1½-inch pipe to 1-inch outlet pipe. Taking the results with the ¼-inch orifice, when the velocity of flow was 0·15 foot per second in the 6-inch pipes, increased to 5·36 feet per second in the 1-inch pipe, the force of ram was 129·2 lbs. per square inch in the 1-inch pipe, 127 lbs. in the 1½-inch pipe, and 14·5 lbs. in the 6-inch pipe. At the dead end of a separate 2½-inch pipe on a branch from the 6-inch pipe, 300 feet distant, ram was got to the extent of 18·8 lbs. With orifices of ⅛ inch, $\frac{3}{16}$ inch, ¼ inch, and $\frac{5}{16}$ inch, and velocities of 1·06, 2·57, 5·36, and 6·75 feet per second, the rams in the 1-inch pipes were respectively 26·9 lbs., 72·8 lbs., 129·3 lbs., and 158·7 lbs. In the 6-inch pipe, with orifices ¼-inch, ⅜-inch, and ½-inch, and velocities of from 0·15 foot to 0·53 foot per second, the rams were from 14·5 lbs. to 51·7 lbs. In the same pipe, when the air-chamber was in service, the ram, with the ½-inch orifice, was reduced to 49·3 lbs., or a little more than half the ram without the air-chamber. From these and other tabulated results, it appears that the force of ram rapidly increased in the same pipe as the velocity of flow was increased; also that the ram rapidly increased as the diameter of pipe was reduced.

The third series of experiments was conducted on a separate extension from the 6-inch pipe, comprising 182 feet of 6-inch pipe, 66 feet of 4-inch pipe, 3½ feet of 2½-inch, 1 foot of 2-inch, 6½ feet of 1½-inch, and 6 feet of 1-inch pipes.

Taking again the ¼-inch orifice, when the velocity of flow for pipes of from 1 inch to 6 inches bore varied from 0·15 foot to 5·39 feet per second, the force of ram increased from 4·8 lbs. in the 6-inch pipe to 66·7 lbs. in the 1-inch pipe. Again, in the 1-inch pipe, with orifices of from ⅛ inch to ½ inch, the force of ram increased from 15 lbs. to 177·5 lbs. per square inch. With nozzles of from ¼ inch to 1 inch, the ram in 2½-inch pipes varied from 22·2 lbs. to 183 lbs., and, in 6-inch pipes, from 4·8 lbs. to 80·1 lbs. per square inch. With the air-chamber in service, and the 1-inch orifice, the ram was reduced to 106 lbs. in the 2½-inch pipe, and to 65·6 lbs. in the 6-inch pipe.

D. K. C.

Annual Meeting of German Gas- and Water-Works Engineers at Salzburg.

(Gesundheits-Ingenieur, 1885, p. 453.)

At the twenty-fifth meeting of this Association, which took place from the 15th to the 17th July last, Mr. Hegener, the manager of the Cologne Gas Works, read a Paper on "Pipe-laying for Gas- and Water-Distribution." Reference was made to the present practice of giving to the metal of the socket of pipes the same thickness as that of the pipe, whatever its diameter, whereas in all pipes above 2 feet in diameter it would be expedient either to thicken the metal at the socket, or to employ a ring of wrought-iron to form the joint; and it was pointed out that though wrought-iron is in all respects preferable as a material for pipes, it is at present but little used. It is necessary, however, before it can be widely introduced, to determine, as is now being done in Berlin, by careful experiments, what is the best plan of protecting pipes of wrought iron against corrosion. In the course of the discussion on the Paper, it was stated that at Düsseldorf it has been decided to substitute wrought-iron for cast-iron for the gas-mains.

G. R. R.

The Effluent from the Berlin Sewage-Irrigation Works.

By Prof. Dr. Alexander Müller.

(Gesundheits-Ingenieur, 1885, p. 475.)

The surface at present under irrigation comprises two districts north and south of the city, with a total area of about 5,000 hectares (12,355·7 acres). The drainage of these districts is discharged into numerous small streams, all of which are tributaries of the Spree. The drainage of the north-eastern districts passes chiefly into the Wuhle, and that of the north-western area into the Panke, while the southern effluent is nearly all carried into the Havel. Owing to the non-completion of the irrigation-works, and the rapid manner in which the drainage of the town was carried out, the northern area was almost constantly flooded, and speedily got into a very bad and swampy condition. Owing to this the effluent was very impure, and it was feared that, partly by means of the water-supply derived from the Spree, and partly by the ice, the inhabitants of Berlin might have the indirect enjoyment of their own sewage. This unfortunate state of things at length induced the Government to undertake searching tests, and to frame stringent enactments. Moreover, some of the adjoining owners of land invoked the aid of the law to defend their interests.

The results are here given of the examination of certain test-samples taken from the Panke in 1883, in order to ascertain to what extent the drainage from the irrigation-works had an injurious effect upon the water of that river for bathing purposes. The samples were three in number, and were taken from various parts of the Panke. The first sample, A, was quite clear and bright, but had a yellowish tinge when seen in a glass vessel; the second, B, was greenish in colour; the third sample, C, taken lower down the stream, more resembled sample A. The microscopic examination corresponded with the appearances above noted. A showed, after standing, only a slight brownish sediment, containing desmids and bacilli, together with a little humus matter. B, a copious, rapidly-increasing, light greyish-green sediment, consisting of different species of desmids and infusoria, together with varieties of leptothrix, that is to say, of such organisms as are regularly to be found in polluted waters, towards the close of the period of self-purification. C presented the appearance of a strongly diluted variety of B.

On making a chemical examination of these samples, it was found that A, which represented the river in its natural condition, was fairly pure, and quite fitted for bathing purposes, notwithstanding its somewhat high percentage of humus. Attention is called to the marvellous self-cleansing power which the River Panke possesses; for while at Bernau (where in summer-time there is very little water) the smell and appearance is pestilential in the extreme, in a distance of less than 2 kilometres, after flowing sluggishly through the market-gardens and meadows, it again presents a wholly innocent and unpolluted character.

Sample B bore signs of being an effluent from the subsoil in the last stage of self-purification.

Sample C might be regarded as a passable bathing water. Details of the analyses of the 1883 specimens are given.

It is also pointed out that in periods of drought, while the irrigation goes on at the usual rate, the volume of the water in the river rapidly diminishes, and the relative proportion of river water to effluent undergoes a great change. Moreover, it has been noticed that from time to time large quantities of untreated sewage find their way into the Panke.

The results of a second examination of the water in the year 1884, which are then given, are very similar to those already quoted. Detailed analyses of the original river water, represented by sample A, and of the effluent represented by B, are given as follows:—

	Constituents in parts per million. A.	B.
Oxide of iron and alumina	0·5	2·4
Lime	97·5	220·3
Magnesia	8·9	18·9
Potash	3·4	6·5
Soda	14·2	99·3
Chlorine	17·5	139·2
Sulphuric acid	12·1	75·5
Nitric acid	..	63·0
Silicic acid	9·0	12·2
Carbonic acid (calculated)	80·3	114·0
Total	243·7	751·3
Deduct for oxygen replaced by chlorine	4·0	31·4
Total	239·7	719·9

Or by arranging the acids and bases, excluding the indifferent silicic acid and the oxides of iron and alumina, the following distribution may be assumed:—

	A.	B.
Silicic acid	9·0	12·2
Oxide of iron and aluminium	0·5	2·4
Carbonate of lime	160·4	213·0
Sulphate of lime	18·2	128·4
Nitrate of lime	..	95·7
Chloride of calcium	..	30·0
Carbonate of magnesia	18·5	39·5
Chloride of sodium	26·8	187·4
Chloride of potassium	3·1	10·3
Sulphate of potash	2·7	..
Total	239·2	718·9

As a general result of the investigations, it is pointed out that the original river water is as pure in 1884 as it was in 1883; that the drainage from the irrigation-works remains equally unaltered; and that the pollution of the river has been traced over the same area as before; that the clarified effluent from the irrigation-works, however, is much inferior in quality to the original river-water, and in times of epidemics must be regarded with suspicion.

G. R. R.

Wollmar's System of Disinfection.

(Gesundheits-Ingenieur, 1885, p. 449.)

This process has now been in use since 1876, and excellent results have ensued in all cases where the material has been rightly employed. It is necessary, before making use of this disinfectant, to thoroughly cleanse the places where it is proposed to introduce it, as traces of previous impurities rapidly set up putrefaction, and nullify the action of the material. An objection hitherto to the general introduction of this system had been the fact that the deodorisation of the excreta is so complete that the manure merchants consider that a compost so entirely devoid of smell can have little value. This, however, has been proved to be a mistake, and as the compound employed locks up the sulphur and ammonia, instead of permitting those substances to escape as ammonium sulphide, the manure is in reality rendered more valuable than it would otherwise be. The analysis by Dr. Fleck of Wollmar's disinfectant is as follows:—

Perchloride of iron	130	Reckoned dry.
Chloride of iron	58	
Hydrated oxide of iron	247	
Water, and water of crystallization	162	
Dry sawdust	153	
Water—the presence of which is indispensable	250	
Total	1,000	

G. R. R.

The Present Position of the Differential System of Excrement-Removal. By J. Kaftan, of Prague.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xvii., 1885, p. 407.)

The municipal authorities of the city of Prague appointed a commission to report upon the best system of sewerage, and on the recommendation of the commission, pronounced in favour of water-carriage. The Author, who was one of the reporters, undertook an inquiry into the plan of Captain Liernur, as at present in use in Holland, in consequence of the sharp attack to which the opinions of the Prague commission were subjected in the recent work of Captain Liernur, entitled "Rational Town-Drainage." The system in use at Amsterdam, Leyden, and Dort, was examined. In the two latter towns, the number of houses dealt with on the plan of Captain Liernur remains stationary. In Amsterdam there were, at the end of 1883, 3,100 houses, with a population of 52,445 inhabitants, connected with the system. Details are given of the machinery at the central station, a building occupying an area of 1,150 square metres; two pumping-engines, each of 50 HP., and three boilers each of 60 HP. have been provided, and it is intended to evaporate the fecal matters by triple effect, to a treacle-like state, and to complete the drying by means of metal cylinders. The expectation of Captain Liernur that each lb. of coal will evaporate 16 lbs. of water is discussed, and the Author states that from his experience in connection with the sugar-manufacture at Prague, it is impossible to attain these results. Indeed, he asserts, from the results of his experiments, that engines whose waste steam is utilized in the apparatus of Robert, require as much as 57 kilograms of steam per HP. per hour, while a good large Woolf's engine will need only 16 or even 14 kilograms of steam per HP. hourly. Liernur reckons the volume of sewage to be dealt with at 7 litres per head per diem, and deducting the weight of the poudrette produced, it will be necessary to evaporate 6·916 kilograms of water per head daily.

The conditions under which Prague (population 250,000) is situated with regard to sewage-disposal are considered, and the Author assumes that the cost of the necessary works for the collection and poudrette-manufacture on Liernur's system would be 40·80 marks (40*s.* 9½*d.*) per head, while a complete water-carriage system of sewerage would cost only 25·50 marks (25*s.* 6*d.*) per head of the population.

The Liernur system in Leyden is applied to one hundred and forty-four houses and two schools. The total volume of sewage dealt with in Leyden from May 1883 to April 1884 was 629,000 kilograms; cost of working, 1248·30 florins; receipts, 424·68 florins, equivalent to an annual expense of 823·62 florins. The selling price of the excreta has fallen from 60 cents per 100 kilograms to 6 cents since the introduction of this system.

At Dort, the central station was closed for extensive repairs; the costly poudrette works erected for this system have been closed for several years. The Author sums up in favour of a water-carriage system which removes the whole of the excreta and domestic waste-water rapidly and safely from inhabited areas.

G. R. R.

The Old Port of Marseilles, the Sewers, and the Cholera during the Epidemic of 1884.

By A. Guérard, Engineer of the Port of Marseilles.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1885, p. 25.)

The greater number of the sewers of the city of Marseilles empty themselves into the old port, either in the line of the Rue Cannebière, or like those of the Rue Breteuil, into the Canal des Douanes. The water in the port is seldom changed, and becomes extremely foul; and, owing to the decomposition of the fecal matters, it emits pestilential odours. Endeavours have frequently been made to induce the authorities to cover over the Canal des Douanes, but hitherto without success. During the recent cholera outbreak, the agitation was renewed, and as the presence of the malady was attributed to the foul state of the port and the canal, the Author undertook an investigation into the causes of the epidemic. The cholera did not originate in Marseilles, it was imported thither. It could not, therefore, be due to the condition of the old port. On a map of the town the Author marked from day to day the localities where the various deaths occurred, and a fac-simile of the death plan thus produced is appended. A Table is also given showing the percentage proportion of the deaths per 1,000 inhabitants, in each of the twenty-one arrondissements, from the time of the outbreak of the cholera on June 27th until the last recorded death on October 31st. The total deaths were 1781, which, in a population of 360,099, is equivalent to a death-rate of 4·94 per 1,000. The map shows that very few deaths took place along the line of the Canal des Douanes, and in its immediate vicinity, and the same may be said of the arrondissement in which the canal is situated, the death-rate being only 1·55 per 1,000. In the neighbouring arrondissement the proportion was 1·99, and it was in these two arrondissements that the death-rate was the lowest. A similar investigation proves that such was the case also in the vicinity of the old port.

All the more striking, then, is the relation which the death-rate bears to the comparative cleanliness of the different quarters, and which the map clearly proves. In the old part of the town, behind the town hall, the death-rate was 7·72; in the tenth arrondissement, also dirty and undrained, it was 6·72, and in the second and fifteenth arrondissements, the rate was 6·17 per 1,000. These quarters are densely populated; they have no sewers nor water-closets, and they are, as a rule, inhabited by the lowest classes of the community, devoid of the most elementary notions of hygiene. The map shows that the sewers had a marked influence for good, as few deaths occurred in streets through which sewers pass, even in the worst parts of the town. The sewers, in some instances, seem to have "drained away the epidemic." A description is given of the method of using the existing sewers, and of the character of the house-connections. Reference is made to the remarkable improvement brought about in the death-rate of Brussels by improved drainage, and the Author states that his observations confirm him in the opinion that the emanations from the sewers are much less dangerous to health than those arising from cesspools.

The water-supply of Marseilles is next considered; the volume distributed amounts to 7,105 litres per second, and it is shown that nothing indicates that the water had any influence upon the spread of the disease. In conclusion, an idea is given of the works which must be undertaken in order to divert the sewage from the port, by the construction of an intercepting sewer, which must be carried out to sea. It is also proposed to convey water into the port by means of the force of waves rising against a breakwater in stormy weather. An estimate of the probable cost is given, the total expenditure being 1,200,000 francs (£48,000).

G. R. R.

On the Composition and Heating Power of Ruhr Coal.

By — SCHEURER-KESTNER.

(Bulletin de la Société Industrielle de Mulhouse, July 1885, p. 375.)

The Ruhr coal, from the Altendorf mine, recently placed on the Alsatian market, is notable as a high-class coal, ranking with the Ronchamp coal. Its calorific power is greater than the sum of the heats of combustion of its elements.

The ultimate average composition of Ruhr coal is as follows:— Carbon, 88·50 per cent.; hydrogen, 4·11 per cent.; nitrogen, 0·99 per cent.; oxygen, 4·82 per cent.; and ash, 1·58 per cent. The heat of combustion, determined by means of the apparatus of Favre and Silbermann, amounts, by the average of these trials, to 16,400 units per pound weight. The heat of combustion calculated in terms of the constituents of a particular sample is as follows:—

	Units.
Carbon, 89·92 per cent., at 14,544 units per pound	13,078
Hydrogen, 4·18 „ at 62,100 „ „	2,596
Total by addition	15,674
Oxygen, 14·90 per cent. = 0·61 hydrogen, at 62,100 units per pound (deduct)	379
Total heat of combustion, by Dulong's formula	15,295

Against this amount it was found by experiment that the heat of combustion of the same sample was 5·7 per cent. more than the sum obtained by the simple addition of the heats of the elements, and 7·4 per cent. more than the heat of combustion calculated by Dulong's formula.

This excess of heat generated by the combustion of the fuel is in accord with the results previously obtained by Messrs. Scheurer-Kestner and Meunier-Dollfus, and it is certain that, for coals, Dulong's formula is not applicable, and that the actual heat of combustion is more likely to be ascertained by the simple addition of the heats of combustion of the carbon and the hydrogen.

The Ruhr coal was tested for evaporative power in the boilers which served for the experiments of 1869. The trial lasted fifty-three hours. The quantity of coal burned was 15,640 lbs., containing 5½ per cent. of hygroscopic water, leaving 14,784 lbs. of dry coal. Of dry ash obtained there was 12·1 per cent.; it contained only 4·3 per cent. of carbon. The weight of dry and pure coal was 12,982 lbs. The water evaporated was 12,742·4 gallons supplied at 80° Fahrenheit, equivalent to 12,215·3 gallons at 32° Fahrenheit. The pressure was 5 atmospheres. The water was evaporated at the rate of 7·82 lbs. per pound of the coal as supplied, 8·26 lbs. per pound of dry coal, and 9·41 lbs. per lb. of pure and dry coal. The temperature of the escaping gases was 273·2° Fahrenheit; that of the air was 55·4° Fahrenheit; and that of the steam 304° Fahrenheit. The gases, by analysis, contained 9·3 per cent. of carbonic acid, 9·2 per cent. of oxygen, 81·5 per cent. of inert gases. The air in excess and the inert gases taken together were proportionally as 43·8 per cent. to 56·2 per cent.

The distribution of the heat of combustion is by calculation as follows:—

	Units.	Per cent.
Heat in the evaporated water	11,043	or 67·3
„ gases of combustion	878	„ 5·4
„ aqueous vapour of combustion . .	508	„ 3·1
Unconverted heat of combustible gases . . .	436	„ 2·7
„ the smoke-particles of carbon	65	„ 0·4
	12,930	„ 78·9
Heat not recovered	3,470	„ 21·1
Total heat of combustion . . .	16,400	100·0

From this statement it appears that there was unrecovered heat to the extent of 21·1 per cent. of the total heat of combustion, arising from local conduction and radiation. The heat lost by imperfectness of combustion is only 3·1 per cent.

D. K. C.

On the Construction of Tungsten and Iron-alloys.

By L. SCHNEIDER.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxxiii., 1885, p. 257.)

The following investigation was made with a view of determining the chemical constitution of the compounds of iron and tungsten, employed in steel-making. An alloy of the specific gravity 9·31, containing iron 68·4, tungsten 28·2, and carbon 1·9 per cent., was coarsely powdered and boiled in hydrochloric acid until the evolution of hydrogen ceased, when the crystalline powder adhering to the surface of the fragments was rubbed off. The metallic powder obtained from several repetitions of the above operation was boiled for several hours in hydrochloric acid, and finally washed with water, boiling potash-lye, alcohol, and ether, and heated to redness in a current of hydrogen. The result was about 40 per cent. of metallic residue made up of two alloys, separable by the magnet, while scarcely a trace of tungsten was dissolved. The larger part of this residue—fully 90 per cent.—

consisted of light steel-grey grains, perfectly unmagnetic, which are well formed octahedral crystals, sufficiently hard to scratch glass, but so brittle as to be easily rubbed to powder in an agate mortar. They contain iron from 24 to 31, tungsten 69·83, and carbon 1·4 to 1·6 per cent. When heated in the air the powder burns with a glimmering light to a brown non-magnetic product, which, when heated in hydrogen, is reduced to tungsten-iron, the crystals preserving their form. No iron is extracted by boiling hydrochloric acid.

In order to compare the behaviour of this iron-alloy with those with other metals, a perfectly unmagnetic ferro-manganese, containing iron 35, manganese 57·6, and combined carbon 5·87 per cent., was powdered and oxidized by heating in the air. This was attended with the production of magnetic oxide of iron, rendering the whole of the powder magnetic, and after reduction in hydrogen, metallic iron could be separated by the same means. The effect of tungsten in modifying the chemical properties of iron when diffused through it, is very marked. This in the particular alloy under examination was found to be completely unaffected by a solution of chloride of copper.

From their microscopic characters, as well as their low specific gravity—3·688—it is evident that the crystals, in spite of their compact appearance, are actually hollow forms inclosing gases.

The magnetic portion of the residue is a blackish grey metallic powder, without distinct crystalline character. It contains iron 68·1, tungsten 27·7, and carbon 4·1 per cent. When heated in air it burns, augmenting about 80 per cent. in weight, and remains magnetic. By heating in hydrogen, a tungsten—iron compound—is reproduced, which readily gives up iron by digestion with hydrochloric acid.

The same alloys were obtained by boiling hydrochloric acid from a pig-iron, containing 23·5 per cent. of tungsten; but the proportion of the magnetic uncrystalline compound is larger than that of the harder tungsten crystals. A highly carburized tungsten steel, containing, tungsten 11, manganese 1·49, and carbon 2·15 per cent., gave, on solution in hydrochloric acid, 13·1 per cent. of residue in the form of a fine unmagnetic powder similar in composition to the crystals previously described, while a soft steel, containing tungsten when digested with dilute acid, only left traces of iron containing tungsten. The general conclusion drawn from these experiments is, that tungsten is not actually alloyed with the iron, but exists essentially in a free state diffused through the mass of the softer metal, and preserving its own characteristic properties. The most notable of these, namely, low specific volume, accounts for the circumstance that, in order to produce very hard steel by tungsten, it must be used in considerable quantity, in which respect it is in marked contrast to other hardening agents, such as carbon and phosphorus, which form chemical combinations with iron.

H. B.

A New Apparatus for the Estimation of Copper. By A. H. Low.

(Proceedings of the Colorado Scientific Society, vol. i., p. 68.)

The apparatus described was devised as the result of numerous experiments upon the electrolytic method of determining copper, with a view to obtaining a more rapid and certain method than that generally used. It consists essentially of a simple electrotyping apparatus, with a parchment-paper diaphragm, instead of the porous clay cylinder. The outer cell is a glass beaker, 1¾ inch diameter, and 2½ inches high, and the inner one a piece of thick glass tube of somewhat smaller diameter, open at the ends. The lower end is ground slightly conical, and the parchment paper diaphragm is stretched across it, and clamped tight by a conical silver ring fitting on the ground part. The upper end of the tube is stopped with a wooden plug bored through the centre to admit an amalgamated-zinc rod which reaches nearly to the bottom, and there is also a groove in the side for the escape of gas. At the bottom of the beaker is placed a platinum electrode, consisting of a circular base-plate as large as the beaker will admit, to which are united, by means of gold solder, several concentric cylindrical walls, about ½ inch high. A strip of platinum, and a wire of the same metal attached to the outer wall, form the connection with the opposite electrode by means of a binding screw. The weight of the platinum electrode is about ¼ ounce troy, and its surface on both sides is about twenty square inches. The tube is surrounded by a spring ring of sheet iron, with two horizontal arms attached, which support it on the top of the beaker, the level of the bottom being adjusted by sliding the tube in the ring.

The solution from which the copper is to be deposited must be always of about the same nature; slightly acid, with sulphuric acid, and contain about forty-five grains of chlorate of potash. The volume should be sufficient to fill the beaker to a depth of ¾ of an inch. When much iron is present in the substance under examination it should be previously removed, as it increases the electrical resistance. When the solution is prepared, a mixture of sulphuric acid and water, in the proportion of 1 to 4, is poured into the inner tube to the depth of about 1 inch, the zinc rod is inserted and connected with the platinum electrode, and the tube is lowered until the diaphragm just touches the surface of the copper solution. The deposition of the metal begins at once, and is finished in from one to two hours, according to the amount of copper present. The weight of the sample operated on is in all cases 1 gram. If towards the end of the operation the solution becomes too warm, the beaker must be cooled by placing it in water to prevent the acid liquor attacking the deposited copper and redissolving it. The operation is completed when bubbles of gas are given off from the platinum electrode, and a drop of the solution no longer discolours sulphuretted hydrogen water. The tube and platinum electrode are then lifted together without disconnecting them, and the latter is immersed in a beaker of water, while the former is returned to its place. The electrical connection is then broken, and the electrode, after being washed first with water and then with alcohol, is dried and weighed. For further use the deposited copper is dissolved off the platinum by nitric acid. Before setting aside the tube it is well rinsed with water to remove the acid from the diaphragm, which will last for several operations. Examples of the application of the method to different copper ore and furnace products are given, and the results are practically identical with those obtained by electrifying with a battery current. The time occupied in the operation was one hour and a half in each case. The apparatus, which was first made and used at the Orgo works of the Boston and Colorado Smelting Company at Denver, can be obtained from Messrs. Eimer & Amend, of New York.

H. B.

On Bessemerizing Copper Regulus in Montana. By T. EGLESTON.

(School of Mines Quarterly, May 1885.)

The process of converting copper regulus into blister-copper, by blowing air through it in a Bessemer converter, has been introduced at the works of the Parrott Silver and Copper Company at Butte City, Montana. The ores treated, quartzose sulphides, with an average assay of 12 per cent. for copper, are divided into two classes. The first class, which is very small in amount, containing 22 per cent., is broken into lumps about 2 inches cube and roasted in stalls, while the second ore, containing 9 per cent., is crushed and dressed up to 18 per cent., and roasted in reverberatory furnaces. These are 54 feet long and 14 feet wide. Wood fuel is used at the rate of one sixth of a cord per ton of ore. The roasted ore contains 22 per cent. of copper and 5 per cent. of sulphur. There are six calcining furnaces capable of roasting 12 tons per day each, or 72 tons for treatment in the blast-furnace, which runs from 70 to 80 tons of ore into regulus per day. The stack of the blast-furnace is an inverted truncated cone, 9 feet high, 4 feet in diameter below, and 5 feet at the feeding door. It is blown with cold blast at a pressure of ¾ lb. to the square inch through nine twyers. According to the quality of the ores the regulus may contain 40 or 70 per cent. of copper.

The regulus from the blast-furnace is concentrated in converters of the Bessemer form, about 6 feet high, and 3½ feet in diameter externally, having a thick lining of "ganister" made of crushed quartz, held together by clay. The interior capacity is about that of an ordinary oil barrel, and takes a charge of 1 ton. The twyers, eighteen to twenty in number, on the side of the converter from 6 to 10 inches above the bottom, are drilled through the lining while soft, and are perfectly horizontal. Their original diameter is about ½ inch, which increases as the lining wears away during the operation. The use of a larger number of twyers, up to eighty or a hundred, has been suggested with a view to shortening the operation, but the advantage of this seems doubtful, as even with the smaller number the twyers are very easily clogged, and require to be constantly watched and cleaned out with an iron rod to prevent stoppage of the blast.

A freshly-lined converter, after standing for somewhat less than twenty-four hours, is charged with coke before it is quite dry, the moisture gradually escaping as it gets heated through. The charge of regulus is then introduced either directly from the ore furnace or after remelting in a cupola, and fills it to a depth of about 8 inches. The converter is then turned up, and the operation is performed as in the ordinary Bessemer process, blast at 5 to 7 lbs. pressure the square inch being supplied at the rate of about 3,500 cubic feet per minute. The rise of temperature at first is very rapid, from the combustion of iron and sulphur in oxide of iron formed in combining with the silica of the converter lining. The flame, at first short and yellowish, becomes smoky and whitish yellow, from the volatilization of lead and zinc oxides. After two or three minutes the foreign metals are mostly oxidized, and only copper sulphides remain in the converter, the sulphur of which commences to burn, giving a large and clear flame of a bright yellow. In fifteen to twenty minutes' time, according to the richness of the charge, the flame becomes clear and continues so to the end of the operation. If any carbon remains in the converter after drying and heating, the flame is greenish on the edges. The time of the operation varies with the quality of the regulus treated. Usually 40 per cent. regulus is brought to 73 per cent in twenty-five minutes, and the latter to 99 per cent. blister copper in half an hour.

When the original regulus is poor, and contains much iron, ground quartz sand is blown from a sand-box through the twyers with the blast to prevent too rapid destruction of the lining, but this operation requires great care in order to prevent chilling.

When the regulus is poor the whole contents of the converter are, in France, poured into a conical mould, to allow slag and metal to separate. The quantity of regulus formed is small, and is found in the first moulds with the blister copper, from which it is easily separated by quenching the mould in water when it is at a dull red heat.

At Butte each converter has a hood with a small chimney, so as to scatter the gases into the air; but in France a stack 160 feet high is used. The slags from the converter at Butte contain 1½ to 3 per cent. of copper. They are basic sub-silicates of iron, and form an excellent flux for the ore furnace.

The regulus of the first operation is either melted or poured from one converter to another, and blown to blister copper in fifteen to twenty minutes. There is very little smoke in this operation, and the flame is short and yellow, or occasionally greenish. The close of the operation is indicated by the cessation of the smoke, and the projection of shots of copper. The temperature produced by the combustion of the sulphur, iron, and other metals, which are in small quantities, is not very high, so that the blister copper is cast at a low heat. It contains from 98 to 99·2 per cent. of copper, and is said to be absolutely free from arsenic and antimony, which are removed by the intensely oxidizing action of the blast. Zinc, iron, and lead, are separated without difficulty. Cobalt is partly removed, but some remains in the copper. On the other hand, nickel and bismuth appear to be concentrated. The blister copper is refined in a reverberatory furnace in the usual way.

After every twenty to twenty-five operations, the converter needs patching with clay and quartz, and when this is carefully done, the linings may be made to last for some months. When the sides are worn too thin, the converter is cooled with a spray of water, and a workman goes inside and stamps in a new lining, which takes about eight hours.

About twenty blows can be made in twenty-four hours. About a ton of fire-clay and quartz are required daily for the repairs of the converters. The labour required is about six men for the converter per twelve-hour shift, and one and an assistant for the repairs.

When the regulus is sufficiently rich to blow to blister copper, a few cwts. of coke are required in the day to keep the converter sufficiently hot; but with a poorer material, requiring a preliminary concentration to 72 or 75 per cent., the sulphur generates sufficient heat, and no extra fuel is required. In the former case, 70 per cent. regulus must be made in the blast-furnace directly from the ore, and then much of the advantage of the process is lost. Whether this operation should be preferred in one or two stages is entirely a question of comparative cost, and although it can be done, it does not usually pay to run directly from low regulus to blister copper at one blowing. At any rate, at Butte it has always been intended to work by the method of blowing in two stages.

The consumption of fuel at Butte is not given by the Author. In France, according to the late Professor Gruner, it is computed that 5 tons of coal, or its equivalent in coke, per ton of copper made, starting from 10 per cent. ores, are sufficient as against 13 to 16 tons required by the Welsh method of smelting.

The use of the process is restricted by the fact, that it is often not practicable to produce coarse metal of 33 per cent. by a single fusion. This contains from 35 to 40 per cent. of iron, while one with only 20 per cent. of copper will contain 50 per cent. of iron. In order to get a regulus of the same richness, about twice the quantity of iron will have to be fluxed in the latter, as compared with the former, and as this can only be done by the lining, the output will be reduced one-half, and the cost doubled. A rich regulus is therefore essential, and if this can be obtained without costing too much, the process will pay. The Author considers that there are certain accessory advantages in the easy removal of arsenic and antimony, and the possibility of the rapid concentration of precious metals in the regulus or blister copper. It remains, however, to be seen whether the complete volatilization of the worst impurities may not be attended with a disproportionate loss of their more valuable contents.

The process, however, cannot be used unless the sulphurous gases can escape into the air without giving rise to compensation claims for damage to cultivation; as there is no way of collecting and condensing them. Where water-power is available, the saving in fuel and labour makes the process of great value.

H. B.

Experimental results on the Electrolytic Reduction of Copper Regulus.[1] By E. Marchese.

In the smelting of argentiferous lead ores containing copper, at the Stolberg works of the Stolberg and Westphalian Company, a certain amount of cupriferous regulus, containing 7 to 8 per cent. of copper, is produced in the lead furnaces. This is calcined and resmelted in order to recover the lead and silver as completely as possible, giving a second regulus with from 15 to 25 per cent. of copper, which may be sold as such to smelting works, or subjected to a further concentration and calcination, giving an enriched regulus with 50 to 60 per cent. of copper. The Author, who is engaged in the electrolytic reduction of copper regulus at Casarza near Genoa, has conducted some experiments on the treatment of these products at Stolberg, in order to obtain data for the establishment of works on a large scale, which are about to be put into operation. The process, as is known from previous descriptions, consists in electrolyzing anodes of copper regulus in a bath containing sulphates of iron and copper, obtained by roasting and lixiviating a portion of the same or a richer regulus, copper sheets being used as cathodes. The plant used in the experiments had previously been in operation in the International Electrical Exhibition at Turin in 1884, and was worked continuously from February 9th to the beginning of April 1885. The material treated was the second regulus, whose average composition was—

Copper 15–16 Lead 14 Iron 41–44 Sulphur 25 per cent.
Silver 16 ozs. 7 dwt. per ton.

This was cast into slabs 600 millimetres broad, 620–640 millimetres long, and 55 millimetres thick. The latter dimension, owing to an error in the adjustment of the moulds, is too large, the proper thickness being 30 millimetres. Forty-two anodes of the above dimensions were used. The solution used in the electrolyzing cells was obtained from the lixiviation of the calcined product of a richer regulus containing—

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[1] "Traitement electrolytique des Mattes Cuivreuses au Stolberg, par E. Marchese," 8vo., p. 64. Genoa, 1885.

Copper 53 Lead 14·4 Sulphur 15·8 Iron 7·65 per cent.
Silver 18 ozs. 6 dwts. per ton.

The whole volume of solution employed during the experiment was contained in a small cistern, less than 2 square metres in area. The dynamo employed was a Siemens No. C 6, giving, according to the makers, with an external resistance of 0·037 ohm, a current of 150 amperes, with a difference of potential of 5·55 volts; the average speed was eleven hundred and eighteen revolutions per minute, the chemical reaction in each cell being computed at about a half volt, the machine was sufficient for working six cells coupled in tension upon the basis of maximum electrolytic work.

The conductors employed were of copper, 10 millimetres diameter, and the cathodes, copper sheets ½ millimetre thick and 600 millimetres square.

The electrolytic cells or basins, which were placed in a single series at the same level, were similar to those in use at Casarza. They are lined with lead and of the following dimensions:—

	Length.	Height.	Breadth.
Inside . .	1,000 millimetres.	800 millimetres.	680 millimetres.
Outside . .	1,160 „	920 „	920 „

Each one contained seven anodes of regulus and eight copper cathodes, and was filled with the sulphate liquor to within 10 millimetres of the top of the cathodes, at which level an overflow lead pipe was fixed, communicating by a channel common to the six cells with the storage tank, whence the liquor passed to a clarifying tank for distribution by a pump which lifted it to a pipe placed opposite to the overflow. The flow through the cells was at the rate of 800 to 1,000 litres per hour.

The amount of copper in solution varied from 3 to 4 per cent., and the iron though continuously increasing, was not brought up to the point of saturation during two months' working.

From the commencement of the experiment on February 9th up to the 15th of March the operations were watched by the machinist who fitted up the plant under the Author's orders, and during that time two hundred and sixty-seven electrical measurements were made with a Siemens and Halske torsion-galvanometer, including determinations of the difference of potential at the machine terminals, strength of current by measurements of the difference of potential between fixed points upon the main conductor whose resistance was known, and difference of potential between the electrodes in each basin. These, though not mathematically accurate, were sufficient for practical purposes. They gave the mean difference of potential at the machine terminals as 5·235 volts, and the average intensity of current at 92 amperes.

Other trials made by the Author on nine different days gave 5·65 volts and 89 amperes intensity. The amount of copper deposited under the latter conditions in eight days was 106·575 kilograms, or 13·322 in twenty-four hours.

Another trial made upon the cathodes of a single cell gave the deposit as 34·145 kilograms in fifteen days, or 2⅓ kilograms per day, corresponding to 450 grams of copper per square metre of cathodes of twenty-four hours.

The copper deposited was entirely free from lead and silver, and contained, according to two different analyses, 99·92, or 99·95 per cent. of fine copper, or was in no way inferior to that obtained electrolytically from blister-copper.

The work due to chemical reaction, considered as a counter-electromotive force, computed by a method proposed by the Author, was found to be from 0·4 to 0·45 volt. The total exterior resistances were about 0·033 ohm. The electrolytic duty, obtained by comparing the intensity of the current with the weight of deposit, was very high. The theoretical deposit corresponding to 89 amperes is in round numbers 2·5 kilograms per day per cell, while the amount realized was 2·261 kilograms, or between 85 or 90 per cent., with 3 to 4 per cent. of copper in the solution. The apparent loss represents the work consumed in the reduction of ferric to ferrous sulphate, or the prevention of the evolution of hydrogen and consequent polarization of the electrodes. A similar duty of 85 per cent. has been realized at Genoa, when the liquor contained not less than 1 per cent. of copper.

The mechanical work consumed in the experiments was not determined, but as a current of 89 amperes at 5·65 volts corresponds to about 50 kilogrammetres per second, or about ⅔ HP., and the efficiency of a good dynamo may be put at 90 per cent., it is certain that less than 1 HP. was consumed.

The works that have been constructed upon the data obtained in the above experiments, are intended to produce from 10 to 12 cwts. of copper per day, corresponding to a consumption of 12 tons of first (7 to 8 per cent.), or 3 tons of second (15 to 20 per cent.) regulus, and cover an area of 324 square metres (18 metres square). The number of cells is fifty-eight, arranged by series of six in terraces. Each cell contains about 25 square metres of anodes, and the same amount of cathodes. The corresponding weights are 2½ tons of regulus No. 2 for each cell, or 145 tons for the whole number of fifty-eight, representing at the works price about 14,500 francs (£580). Of this one-half may be taken as locked up, or about £320.

The corresponding lock-up of copper in the cathodes, which require about three months to reach a merchantable thickness, may also be taken at one-half or forty-five days at 580 kilograms = 26,100 kilograms, worth at present prices about 32,000 francs (£1,280). The total stock immobilized will therefore be about £1,600 for a production of 210 tons of fine copper per annum, an amount which will not seem excessive when compared with the ordinary tedious processes of smelting copper ores by alternate calcination and fusion, which sometimes require years for their completion. At any rate this difficulty has not been found to interfere with electrolytic refining where the anodes are nearly pure copper, and liquors kept saturated with crystallized copper sulphate are required, which must be changed as soon as a very small percentage of ferrous sulphate has been formed. The loss of interest upon the material in use will, the Author believes, be more than compensated by the extra price obtained for the product, which is worth from £5 to £5 12*s.* more than best selected copper, on the annual product of 210 tons about £1,200. So that the capital represented by the material in use may be considered as producing 75 per cent. per annum interest by the better price obtained for the material.

H. B.

The Smelting of Auriferous Ores at Zalathera in Transylvania.

By — Beaugey.

(Berg und Hüttenmännische Zeitung, vol. xliv., 1885, p. 242.)

The ores raised in the different mining centres of Transylvania, more particularly in Abrud-Banya Verospatak Nagyag, &c., are now treated at Zalathera, most of the smaller works having been closed in consequence of the diminished value of the produce. The free native gold is extracted by amalgamation at the mines, and the concentrates of pyrites and other minerals are treated by Hauch's combined dry and wet processes, which has replaced the old method of repeated calcination and smelting for regulus, the removal of the precious metals partly by lead, and partly by amalgamation, and the final concentration and refining of the copper in the desilverized residues; a tedious series of operations, requiring nine months for their completion, and attended with a loss of about 8 per cent. of the gold and 20 per cent. of the silver contents. The new process, besides being very much quicker and producing a better quality of copper, allows of the recovery of some of the non-metallic contents of the ore—tellurium, sulphurous acid, sulphur, &c.

The ores, essentially iron pyrites, in the condition of dressed slimes with 15 to 20 per cent. of quartz, are classified according to their contents in precious metals (auriferous silver with about equal parts of gold and silver), into poor, 0 to 11 ozs.; semi-rich, 12 to 24 ozs., and rich, above 24 ozs. per ton. The yield of regulus may vary from 0 to 65 per cent. in each category. The tellurium ores of Nagyag are divided into three classes, the first containing above 1 per cent. of auriferous silver (with more gold than silver), and the last below 0·5 per cent. The proportion of tellurium is from 4 to 5 per cent. The yearly production of the mines is from 1,400 to 1,600 tons with 7 to 10 ozs., or a total of about 7,000 ozs. of gold, and about 8,000 ozs. of silver. The series of operations in the new process are as follows:—

1. Extraction of gold and silver.

(*a*) Roasting.

The semi-rich ores, are roasted and partly fritted in heaps; part are left unroasted, and the remainder are passed through Bode's shelf-furnaces, which have five or seven shelves 2 metres long, 1 metre broad, and 10 centimetres thick. The ore passes from one to the other, and is finally removed by a valve in the sheet-iron bottom-plate. The sulphur is reduced from 40 to 6 or 8 per cent. The sulphur gases are utilized in the production of sulphuric acid and sulphur.

(*b*) Fusion for coarse metal.

The calcined ores, mixed with about equal quantities of ores previously burnt in heaps, furnace products, and lead-slags are run for coarse metal in a blast-furnace about 15 feet high and 4 feet in diameter. The blast is supplied at the rate of 11 cubic metres per minute, at 2 to 3 centimetres mercury pressure. The product, containing 16 to 23 ozs. of gold and silver, is essentially a basic-ferrous sulphide, with about ½ per cent. of copper and 28·6 per cent. of sulphur.

(*c*) Extraction with sulphuric acid.

The coarse metal of operation 1 *b*—when ground in a Bruckner mill—is digested with sulphuric acid of 20° to 22° Baumé, in covered wooden tanks lined with lead, the contents being stirred by an agitator. The cover has three openings: the first with a funnel for charging; the second for taking away sulphuretted hydrogen; and the third for burning the latter gas when there is a deficiency of sulphuric acid for working the sulphur-reviving process. The tank being nearly filled with acid, the ground metal is added in progressively small quantities up to a total of 8 cwt. in twelve hours, solution being promoted by stirring and heat. The contents are then allowed to settle for six hours, when the liquor is decanted, and the solid residue is removed. This has lost about one-half of its original amount of iron and sulphur, and contains 3·5 per cent. of copper, 36 per cent. of iron as Fe_2S, and 60 to 80 ozs. of gold and silver. The green vitriol liquors, after clarifying, are crystallized.

(*d*) Smelting auriferous residues.

The partially desulphurized coarse metal is next smelted in a small blast-furnace with lead products (lead ores, litharge, test-bottoms, &c.), for rich lead and coppery regulus, rich telluride ores being added in small quantities. The rich lead contains at least 150 ozs. of gold and silver, and the regulus from 30 to 40 ozs. The latter is, however, almost free from gold, which is mainly concentrated in the lead. The slags of this operation are used as flux in the first fusion for coarse metal.

(*e*) Cupellation of rich lead.

This is done in elliptical tests, in quantities of about 4 tons, which are worked off in about thirty-six hours. The resulting alloy, with 42 per cent. of silver, and 52 per cent. of gold is delivered to the mint for further treatment.

2. Copper extraction.

(*a*) Extraction of lead regulus. The regulus from the lead furnace, containing iron about 50, copper 9·5, and lead 10 per cent., is treated with acid in the same way as the coarse metal, the operation being more difficult on account of the formation of sulphate of lead. This gives a product with about 16 per cent. of copper, which by two or three subsequent fusions with lead is brought up to 25 per cent. The concentrated regulus when ground is treated with strong acid (66° B.) in thick cast-iron pans for about twelve hours, when the acid liquor is run into a lead-lined vat, containing a copper plate, to decompose any silver sulphate formed, and is allowed to settle. The residue consists mainly of copper and sulphate of lead, and is very rich in precious metals. It is returned to the lead furnace, while the liquor, when crystallized, gives a mixed (copper and iron) vitriol, which is saleable, but may be much improved by partial calcination, solution, and recrystallization, which removes much of the iron.

(*b*) Copper precipitation.

This is effected by iron in Hauch's continuous rotary apparatus, described in the same journal for 1876, p. 396.

3. Recovery of bye-products.

(*a*) Tellurium. The rich ores of Nagyag and Offenbanya, containing 1 to 5 per cent. of tellurium, are treated by Lowe's process, introduced in 1854. The product contains 75 per cent. of tellurium, 20 to 25 per cent. of copper, besides arsenic, antimony, and iron. Gold and silver remain in the residues, which are returned to the lead furnaces. From 2 to 3 cwt. of crude tellurium are produced annually, which, when there is any demand, is sold for £4 to £5 per kilogram.

(*b*) Production of sulphuric acid.

The greater part of the gases of the roasting-furnaces are utilized for this purpose, 1 ton of ore giving 1·32 ton of 50° chamber acid; about 1,000 tons are produced annually, of which the greater part is used in the coarse metal extraction, only a small proportion being concentrated to 66° B.

(*c*) Production of sulphur.

This is done by mixing the sulphuretted hydrogen from the extraction process with sulphurous acid from the roasting furnaces, or when necessary, from the combustion of a part of the sulphuretted hydrogen. The reaction takes place in wooden towers, the sulphuretted hydrogen being introduced near the bottom, while the sulphurous acid is forced in at a higher level by a fan. The towers, about 30 to 35 feet high, are fitted with horizontal shelves, over which a solution of chloride of calcium is kept flowing. This prevents the formation of pentathionic acid, which is always produced to some extent when water is used, and the sulphur deposit is more flocculent and easily filtered.

The precipitated sulphur when washed is melted under water at a pressure of $1\frac{3}{4}$ atmosphere, whereby the residual chloride of calcium dissolves, and calcium sulphate remains as a crystalline powder in suspension, while the molten sulphur subsides, and can be drawn off by a valve at the lower end of the retort. A small amount of milk of lime is added, which saturates any free acid and protects the metal. Sulphide of calcium is also formed, and removes any arsenic as a sulpho-salt. The daily production of sulphur is from 4 to 5 cwt.; but this is mostly converted into bisulphide of carbon, for which there is a considerable local demand as a protection of vines against the attack of the phylloxera.

H. B.

On the Electric Conductivity of Mercury and Pure Metals at Low Temperatures. By Messrs. CAILLETET and BOUTY.

(Journal de Physique, vol. iv., 1885, p. 297.)

The Authors first refer to previous experiments made at temperatures above zero Centigrade, from which have been deduced the formulas

$$r_t = r_o\ (1 + a\,t)$$
$$r_t = r_o\ (1 + a\,t + \beta\,t^2)$$

for small and large ranges of temperature respectively. The coefficient a is stated not to differ much for various metals from the fraction $\frac{1}{273}$, which represents the coefficient of expansion of gases. The object of the present memoir is to discover whether the metals observe the same law of conductivity at very low temperatures, viz., between the range 0° and −123° Centigrade. The variation of electric resistance was measured by the Wheatstone bridge, and of temperature by a hydrogen thermometer, the same instrument being used throughout the experiments.

Mercury.—The mercury employed was the mercury of commerce specially purified. The mean coefficient of variation of resistance per degree of temperature down to −40° Centigrade is 0·000804, and there is no apparent change in the coefficient while the mercury remains liquid. On the solidification of the mercury there is a quick movement of the galvanometer needle, the resistance falls suddenly to a quarter of its previous value, and then diminishes regularly at a rate given by the following formula, in which $\rho - 40$ is the resistance of solid mercury at −40°, its resistance at any temperature t lower than −40° being

$$\rho_t = \rho - 40\,\frac{1 + a\,t}{1 - 40\,a},$$

in which $a = 0{\cdot}00407$. This formula is deduced from fifteen experiments between the temperatures of − 40° and − 92°·13 Centigrade.

As regards solid metals the Authors find that the formula $r_t = r_o(1 + a\,t)$ represents very closely the diminution of resistance with fall of temperature in which the coefficient a has the values given in the accompanying Table :—

Metals.	Limits of Temperature. ° C. °	a.
Silver	+29·97 to −101·75	0·00385
Aluminium . . .	+27·70 „ −90·57	0·00388
Magnesium . . .	0·00 „ −88·31	0·00390
Mercury	−40·00 „ −92·13	0·00407
Copper	−23·00 „ −122·82	0·00423
Tin	0·00 „ −85·08	0·00424
Iron	0·00 „ −92·00	0·0049

As regards platinum the experiments were made on chemically pure metal, and the average of nine experiments between + 29°·16 and − 94°·57 gave—

From	+29°·16 to −24°·04	$a = 0·00301$
„	−40·18 „ −59·31	$a = 0·00333$
„	−63·62 „ −94·97	$a = 0·00342$

The previous formula therefore is not applicable to this metal, but the following formula represents the results :—

$$r_t = r_o(1 + 0·003\,t - 0·0000055\,t^2).$$

The Authors propose to extend their researches to still lower temperatures.

E. F. B.

On the Theory of the Gramme Dynamo. By Prof. Mascart.

(Journal de Physique, vol. iv., 1885, p. 341.)

In this Paper some of the physical problems involved in the working of the Gramme dynamos are treated mathematically. The magnetic field is assumed to be uniform and symmetrical with regard to two rectangular planes passing through the axis of rotation, and the magnetization of the soft iron to be constant, and brought about by the superposed influence of the external magnetic field, and the induced current.

If I be the quantity of the current in the external circuit, and the revolving armature makes n revolutions per second, then the work produced is

$$W = n\,I\,E.$$

This last factor (the electromotive force) depends upon the magnetic field, and the angle of inclination of the brushes to the neutral plane. It is constant if the field magnets are excited by a special current, and is a function of the quantity of current alone if the magnetic field is produced by electro-magnets excited by the induced current.

The angle of inclination (θ) of the brushes to the neutral plane is determined practically by the condition that there shall be no sparks. These are dangerous when the brushes break contact, and do not occur when there is a constant potential unaffected by the introduction of the coil connected with the external circuit through the brushes, which must possess electromotive force sufficient to produce in it the current $\frac{I}{2}$. This electromotive force is due to the external field magnet, opposed by the magnetization produced in the ring by the current, and if the latter is assumed to be proportional to the quantity of current, then

$$f^1(\theta) = \frac{1}{4\,n\,\pi}(r + n\,r'),$$

where r is the resistance of one spiral, and $n\,r'$ an imaginary resistance proportional to the velocity.

The Author next considers the lost work due to the passage of the current through the external resistance, and to the mean resistance of the armature. He also takes into consideration the loss shown by Joubert to be caused by making and breaking contact, which is reduced to a minimum when a coil consists but of one spiral.

The excess of energy produced over that wasted, or the useful work per unit of time, is

$$U = n\,I\,E_1 - R\,I^2$$

in which R is the sum of the resistances, and for a determinate angle (θ), E_1 is a function F (I) of the quantity of current alone;

then $$U = n\,I\,(F)\,I - R\,I_2,$$

and the efficiency

$$a = \frac{U}{W} = 1 - \frac{R\,I}{n\,(F)\,I},$$

which for the maximum of work is shown not to exceed 0·5, and only to be equal to 0·5 when the field magnet is constant.

For a given machine the differential f' (θ), and the angle θ, increase with the quantity of current, with the velocity, and inversely as the total resistance.

E. F. B.

Electric Lighting of the Central Railway Station, Strasburg.

By C. Delpeuch.

(Revue Générale des Chemins de fer, July 1885, p. 3.)

The new central station at Strasburg, which has been open about two years, covers an area of 86½ acres, and is lighted entirely by electricity. During the past two years the light has acted without interruption, and it is stated that the experience already gained warrants the conclusion that the lighting of large stations by electricity may cost less than lighting by gas, whilst offering greater security.

The lighting of Strasburg central station is effected by two absolutely distinct systems. First, the principal installation serving the passenger-sheds, the offices, the platforms, ways, goods-sheds, and court. Second, the minor installation for lighting the engine-house and its accessories. The light is derived from arcs and from glow-lamps.

For the principal installation the machines are contained in one building to the north of the station, in wood and brick, about 197 feet long and 65½ feet wide, divided into the boiler-house and engine-house. There are four steam-boilers, of the locomotive type, placed in line, the smoke-boxes being connected with an underground flue to the chimney, which is 6½ feet in diameter and 82 feet high. There is room for more boilers if required. One of the four boilers is employed to heat the offices during the day, and is a spare boiler at night in case of need. There are two batteries of three condensing steam-engines, one of which drives the dynamo machines for arc-lighting; and the other drives the machines for lighting by incandescence. The engines are compound, making 150 turns per minute. With a pressure of 8 atmospheres during an admission of 22 per cent. into the small cylinder, they develop 32 HP.; cutting off at one-third, they can develop 45 HP. Four out of the six steam-engines are at work at one time, one third of the power being in reserve. Preparations have been made for twenty-two Siemens machines and five Edison machines; but there are at present only twelve Siemens machines, of which two are in reserve, serving five Siemens differential lamps; two Siemens machines, each serving six differential lamps; three Edison machines for two hundred and fifty lamps of 16 candles; and one Edison machine for four hundred lamps of 16 candles, in reserve. The Siemens machines have a speed of 1,160 revolutions per minute, and produce a current of 9 amperes and 350 volts, absorbing 5 HP. An Edison machine for two hundred and fifty lamps requires 30 HP., producing a current of 187 amperes.

The Siemens machines serve sixty-two arc-lamps, by which the passenger- and goods-departments are lighted. The lamps in the passenger-department are suspended to two pulleys by counter-weighted chains. The current arrives at the lamp by one pulley, and leaves it by the other.

The copper conductors which form the circuit vary in diameter from 0·16 inch to 1·10 inch. Outside the buildings they are covered with wire, and buried 3¼ feet below the surface. The Siemens lamps have a single pair of carbons, of which the available length is 2·28 inches, lasting ten hours. Each arc lamp gives, it is stated, a light of 800 candles, about 105 carcels. The Siemens lamps are placed at a height of about 18 feet above the platforms, and 114 feet apart; and those in the 6-feet spaces are about 29 feet above the ground, and from 260 to 330 feet apart. The light is steady, regular, and sufficient.

The chief conductors for incandescence-lighting consist of two half-round bars of copper, insulated and placed face to face in an iron tube, also insulated. The wires vary in diameter from about ¼ inch to 0·039 inch (1 millimetre) next the lamps, which are of 16 candles and 10 candles.

The service is conducted by fourteen employees.

The total outlay on the installation amounted, at March 31, 1884, to £12,240. During the three months ending March 31, 1884, the cost for lighting, including an allowance at the rate of £12 per cent. per year for interest and renewal, amounted to £1,021, distributed as follows:—

	£.		d.	
For arc lamps (59,755 hours)	687,	or	2¾	per lamp per hour.
For 16-candle lamps (142,194 hours) .	149	,,	¼	,, ,,
For 10-candle lamps (211,924 hours) .	185	,,	2	,, ,,
	£1,021			

Second Installation.—The machines are lodged in a shed 65 feet by 32½ feet, near the engine shed. There are two semi-portable compound engines of 20 HP., four Siemens machines, one Edison machine, and one Schuckert machine. The Siemens machines serve twelve differential lamps of 350 candles, by which the engine-shed, coal-wharves, and neighbouring lines of way are lighted. The Edison machine serves three lamps of 16 candles, ninety-one lamps of 10 candles, and two lamps of 8 candles, in the offices and accessories. The Schuckert machine supplies a current of 17 amperes, serving three lamps of 3,000 candles each, placed at an elevation of 65 feet. Five employees are engaged. The installation cost £2,646.

The working cost for lighting in the three months ending March 31, 1885, including capital charges, amounted to £245, and the total working costs per lamp per hour were as follows:—

	d.
Per arc-lamp per hour (15,426 hours)	3¾
Per lamp of 16 candles (3,857 hours)	0·42
Per lamp of 10 candles (52,706 hours)	0·32
Per lamp of 8 candles (2,571 hours)	0·29

From the results of comparative statements it appears that the electric lighting of the Strasburg station cost one-third less than the lighting by gas would have cost.

D. K. C.

A Standard of Light. By JOHN TROWBRIDGE.

(The American Journal of Science, vol. xxx., 1885, p. 128.)

The Author thinks the adoption by the Paris Conference of 1881–84, of the light emitted by a surface of platinum at the point of solidification as a standard of light did not assort well with discussions, which reaffirmed the C.G.S. system of units; as although it might be a fixed point in nature, it had not been shown how this point could be connected with the units of heat and work, and electrical energy. As there ought to be such a connection, the suggestion of Schwendler that the light emitted by a strip of platinum rendered incandescent by a known electrical current should be adopted as a standard, seems in the Author's opinion to merit more attention than it has received. The first to propose such a standard was Dr. John W. Draper of New York, in 1847 (Scientific Memoirs, p. 45).

The Author found upon trial that there were very great difficulties in the use of fine platinum wire as a standard, on account of the necessity of measuring light and potential of current at the same instant, the wire fuzing before the measurements could be completed. He succeeded, however, with a strip of platinum foil placed in the shunt circuit of a small dynamo machine, the light from which could be maintained very constant with the proper speed and suitable adjustment of resistances. The light emitted by the platinum was measured by means of a Ritchie photometer, and the electric current by a tangent galvanometer and Thomson quadrant electrometer. The range of the indications of the electrical instruments was comparatively small, while the light varied enormously, the difficulty of the method being that of measuring a strong current with accuracy.

After failing to measure changes in the heat radiated by glow-lamp by means of a thermo-junction in the centre of the carbon loop, the Author substituted a loop of extremely fine platinum wire to form one branch of a Wheatstone bridge, a similar wire being placed in the other branch. This method seemed to be quite sensitive, the results of the experiments leading the Author to think that a bolometer strip of definite surface could be placed at a fixed distance from a carbon loop of known dimensions inside an exhausted glass vessel. The amount of radiation which the bolometer strip received being calculated, the standard of light might be based upon the point of incandescence which would give a definite radiation at a fixed distance. The energy produced by rays of different refrangibility could not be thus distinguished, but variations in the amount of energy received were indicated by the bolometer strip, while the difference in colour of the light of the glow-lamp made the observer at the photometer entirely uncertain of his measurements.

The Author next compared the radiation from a platinum strip with that from a thin brass vessel containing water, by means of a thermopile provided with the customary cones, a series of diaphragms of thick cardboard extending between the radiating surface of the vessel containing water and the platinum strip. This arrangement was extremely sensitive; a short coil galvanometer was connected with the thermopile, a movement of a centimetre in the position of the faces of the pile being sufficient to drive the spot of light from the galvanometer mirror off the scale, corresponding to a movement of nearly 50 centimetre scale divisions. One observer tested the light photometrically, whilst another observed the galvanometer, with the result that with similar photometric observations the thermopile indicated a large change in the amount of heat received.

In conclusion the Author thinks it possible to assume as a practical standard, a carbon loop in an exhausted vessel raised to such a point of incandescence that it will radiate a definite amount of energy, this energy being measured by a bolometer strip or the thermopile at a definite distance from the carbon loop, this would have a greater range than an incandescent strip of platinum placed in free air. The latter method, however, for the incandescence which produces a light similar in colour to that of a sperm candle is extremely sensitive, and can be made more exact than present photometric tests. Both methods have the great advantage of substituting a measure of energy for a relative indication by the eye, which is not connected with any absolute measurement.

E. F. B.

On a Differential-Resistance Thermometer.

By T. C. Mendenhall.

(The American Journal of Science, vol. xxx., 1885, p. 114.)

This consists essentially of a mercurial thermometer having a greatly enlarged bulb, so that the stem may have a diameter of something like a millimetre, and still keep the scale tolerably "open." There runs down through the stem a fine platinum wire of 0·08 millimetre in diameter. The lower end may be secured in the bulb, so that it is kept straight in the bore of the stem, and at the lower end a heavier wire is sealed in the glass, so that metallic contact can be made with this wire both at the upper end and through the mercury at the lower. The resistance between these two points evidently depends largely on the length of the platinum wire which is above the mercury in the tube, and this will depend upon the temperature to which it is exposed, the resistance diminishing with rise of temperature by an amount equal to the difference between that of the platinum wire which disappears, and that of the mercury which takes its place, less the increase in the resistance of the platinum wire and the mercury due to rise of temperature.

The Author considers this method has an advantage over the use of a simple resistance coil (which the late Sir William Siemens applied in his well-known Electrical Pyrometers and Thermometers), in that the change in resistance accompanying a given change in temperature is much greater, and may in fact be made as great as desired. As a result the telephone may be substituted for the galvometer in the resistance measurements, or less sensitive galvanometers may be used.

E. F. B.

On the Manner of Detonation of Explosive Mixtures.

By A. Witz.

(Journal de Physique, vol. iv., 1885, p. 311.)

It is possible to reproduce artificially the phenomena of explosion and expansion which occur behind the piston of gas-engines, by experimenting upon a cylinder, with a piston movable at variable velocity, and surrounded with a jacket of water or steam. The Author experimented upon explosive mixtures of illuminating gas and air, of which the combustion does not occur instantaneously, the time necessary for the pressure to attain its maximum depending not only upon the composition of the mixture, but upon the extent of the cooling-surface, and the rapidity of expansion.

Two conditions are necessary for combustion to proceed in a gaseous mixture. In the first place the gas must be inflammable, that is, combustion must be attainable by elevation of temperature; in the second place, the quantity of available heat must be such as to raise the neighbouring gas to the temperature of ignition. The velocity at which the combustion proceeds depends not only on the character of the mixture, but is effected by any cause which lowers the temperature, such as loss by radiation and rapid expansion. As regards the proportion of air to gas, 1 portion of gas to 4 portions of air is ignited with difficulty by the electric spark, whilst a proportion of 1 to 13 cannot be so ignited, but may be by a jet of flame at atmospheric pressure.

According to Messrs. Mallard and Le Chatelier, the maximum velocity of combustion corresponds to a mixture of 1 portion of gas to 5·85 portions of air, and is then equal to $1\frac{1}{4}$ metre per second; whilst in a more diluted mixture it was found to be as low as $\frac{3}{10}$ of a metre. The Author's figures agree with those of the observers cited, but vary with the velocity of expansion. The velocity may be observed in a piston in the following manner. Suppose the velocity with which the piston moves forward is equal to that at which combustion proceeds; the combustion will take place according to the same law as the expansion, and a variation at constant pressure will result; a similar variation is conclusive as to the equality of the velocity at which the flame proceeds and the piston moves forward. Thus for the same mixture, a curve of expansion may be obtained which remains parallel to the axis of volumes with varying velocities of piston.

As regards the cooling action of the cylinder, this varies in the proportion of the ratio of the surface to the volume, and the power $1 \cdot 203 + 0 \cdot 0005\,\epsilon$ of the excess ϵ of the internal over the external temperature; at about 2,000° this is equal to 2. Messrs. Mallard and Le Chatelier found this value between the limits of 600° and 2,700°; the mean of which is 1,650°. As the pressure of the burnt gases remains almost constant in these experiments, and does not exceed 1½ kilogram, in the cases from which the calculations have been made, the important action of variation of pressure is almost entirely eliminated.

E. F. B.

Reflectors of Nickel-plated Steel. By — Rouderon.

(Revue Générale des Chemins de fer, July 1885, p. 17.)

On the Northern and other railways of France, trials have been made of various metals or alloys, in substitution for the costly reflectors hitherto employed, constructed of copper plated with silver. In 1884, Mr. Sartiaux, on the Northern Railway, made several trials of nickel-plated sheets of steel, with satisfactory results. With mild steel sheets, plated with nickel $\frac{1}{10}$ of the thickness, costing about 11*d.* per lb., reflectors can be constructed at a cost of from one-half to two-thirds the cost of those in silver-plated copper. Photometrical tests have shown that reflectors in nickel-plated steel possess a reflecting power equal to that of the silver-plated reflectors; and that whilst, at the end of a year of use, the silver-plated reflector loses 20 per cent. of its reflecting-power, the nickel does not lose 10 per cent. The nickel reflector will also wear longer than the silver, as the coat of the reflecting metal of the former is three times as thick as that of the latter.

D. K. C.

Summary of Experiments made by the Swiss Artillery in 1884.

(Revue d'Artillerie, vol. xxvi., 1885, p. 348.)

Two steel Krupp guns, of 12 centimetres bore and hooped, were modified to allow the use of a percussive apparatus for ignition, which had been successful with an 8·4-centimetre gun; the results in this case being also satisfactory, it was adopted by the committee. The gas-check was of copper, and the committee proposed that two guns should be made of bronze mandriné, in order that the national industry might be enabled to take part in the armament of the country.

The bore of 12 centimetres, being small for a siege piece, it was desired to increase the effect of its shells. Two shells, made at the Gruson Works, were fired in comparison with ordinary shells and powder charge. The result gave no marked superiority for the Gruson shells, and as their preparation was longer and more complicated, further trials were suspended. Experiments were made to determine the influence of eccentricity in projectiles on the accuracy of their range, and the limits to be allowed in their manufacture. As an eccentricity of 2 milimetres had a sensible effect on the accuracy, the limit was reduced to 1 millimetre.

Experiments with Shrapnel shell, with rear chambers and double-action fuzes for long ranges, resulted in frequent bursts in the bore, due to premature action of the striking apparatus of the fuze. This was overcome by shortening the striker; a disk of hardened lead was placed underneath, and a spiral spring above it; at the same time the rear ring of the Shrapnel was modified.

Advantage was taken of these trials to study the effects of Shrapnel. They were charged with hard lead balls of 2 calibres, weighing 15 and 12·5 grains, 395 to 400 balls of 15 grains, and 475 to 480 of 12 grains. At 3,000 metres the Shrapnel with small balls gave one-fourth more hits than those with large balls. The number of planks touched was also slightly greater with the small balls. At the same range the penetrative force of the small balls seemed to be equal to the larger ones, and the committee adopted balls of 12·5 grains.

The bodies of shells made in Switzerland of steeled wrought-iron were generally deformed on impact, and the heads remained unbroken, whilst those of Krupp, of steel, were uninjured and the heads always broken.

The carriage was furnished with two shoes specially destined for skidding, but provided with chains to allow the skidding during firing if necessary.

A model ammunition case, containing five projectiles or ten cartridges, each case for projectiles containing six fuzes and ten percussion tubes, was established, and each gun allotted two hundred rounds of ammunition and ten extra cartridges. Powder of 16 to 18-millimetre size of grain was used, but pressure being too high the charge was reduced to 4·25 kilograms. Various samples were tried, wood-powder, octagon and pentagon. Octagon gave the best results. The size of the grains was varied from 15 to 19 millimetres without any inconvenience. A transportable platform proposed, by Lieutenant-Colonel Greesly, was tried with results which give reason to hope that such platforms will constitute a notable progress in guns of position.

A 12-centimetre mortar, fitted with percussion ignition, was tried with a Greesly transportable platform, and also a field-carriage. The mortar was made from a 10·5-inch gun, shortened by 0·50 millimetre and bored out to 12 centimetres; both platform and carriage were adopted for service use.

A short 15-centimetre bronze gun, which was useless after heavy firing, was re-tubed with bronze to see if it could be rendered serviceable. The projectiles were rotated by copper bands. At first the tube behaved well, but gradually it projected and separated itself from the gun; a cap was then screwed on the muzzle, but the extension still proceeded, and the re-tubing of bronze guns was abandoned.

A ten-barrel Gatling gun was tried. The barrels were those of Gras rifles. The mechanism worked well up to one thousand two hundred rounds per minute; at known distances the accuracy was good, but at great and unknown distances it was poor. The result of the experiment was the adoption of a six-barrel gun. To avoid premature bursts of shells in the bore, shells were fired with ordinary and a binary powder; also a bursting composition supplied by the Federal Powder-Administration. The binary powder was composed of 87 saltpetre and 13 charcoal. and 80 saltpetre and 20 charcoal. The bursts were much weaker than with ordinary powder. The initial velocity of a charge of binary powder was much less than the ordinary, but the pressure was also much lower than usual.

J. H. R. W.

On a Method of producing Cane Sugar from Starch by Electricity.

(Dingler's Polytechnisches Journal, vol. cclvii., 1885, p. 298.)

This method, due to L. Aubert and V. Giraud of Lyons, depends upon the formation of saccharose from starch and water, according to the equation

$$2\ C_6H_{10}O_5 + H_2O = C_{12}H_{22}O_{11}.$$

The same result is also obtained by the combination of equal molecules of starch and glucose; then

$$C_6H_{10}O_5 + C_6H_{12}O_6 = C_{12}H_{22}O_{11}.$$

The practical method of obtaining these results is as follows:—100 kilograms of potatoes are heated to 100° Centigrade in 5 cubic metres of water, with 5 kilograms of sulphuric acid, and a trace of nitric acid, until the starch is dissolved. An electric current of 11 amperes is then passed through the solution between electrodes of antimonial lead, the direction of the current being changed at intervals. In about two hours' time the solution is tested with tincture of iodine and alcohol, and if no coloration or precipitate is produced the current is interrupted, and carbonate of lime and hydrate of lime, the latter in considerable excess, are added to remove dextrine and unchanged glucose. Previously to filtration and saturation of the lime with carbonic acid, some basic acetate of lead is added to remove the colouring matter, which otherwise would interfere with the crystallization.

After concentration of the liquid in the usual way, the syrup is allowed to crystallize, which however takes somewhat longer than ordinary sugar-syrup. The composition of the crystallized product is as follows:—

Water	6·95
Ash	3·67
Grape sugar	1·00
Cane sugar	88·38
Specific gravity	1·502
Specific rotary power	+68·6°

H. B.

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